I-394 Minneapolis, Minnesota, Analysis Plan

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16. Abstract This AMS Analysis Plan for the Interstate 394 (I-394) Pioneer Corridor outlines the various tasks associated with the application of the ICM AMS tools to the corridor in support of a benefit/cost assessment of the proposed strategies. The report provides a brief description of the Pioneer Corridor in Minneapolis, Minnesota, and the methodology used for the AMS. It lays out ICM strategies that will be tested, and provides a list of the AMS scenarios. This report then defines performance measures that will be utilized in the analysis of the ICM strategies on the Pioneer Corridor and sets out the simulation model validation requirements and the data needs for this calibration. Finally, the last two sections of this report present an overview of the Pioneer Corridor AMS document that will be developed to summarize the results of the AMS effort and provides a schedule and a resource guide for the AMS tasks.			
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Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction and Background

The objective of the ***Integrated Corridor Management (ICM)*** initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The ICM initiative aims to pioneer innovative multimodal and multijurisdictional strategies – and combinations of strategies – that optimize existing infrastructure to help manage congestion in our nation's corridors. There are an estimated 300 corridors in the country with underutilized capacity (in the form of parallel transit capacity (bus, rail, bus rapid transit (BRT), etc.) and/or arterials and underutilized travel lanes) that could benefit from ICM.

The maturation of ITS technologies, availability of supporting data, and emerging multiagency institutional frameworks make ICM practical and feasible. There are a large number of freeway, arterial, and transit optimization strategies available today and in widespread use across the United States. Most of these strategies are managed locally by individual agencies on an asset-by-asset basis. Even those managed regionally are often managed in a stove-piped manner (asset-by-asset), rather than in an "integrated" fashion across a transportation corridor. Dynamically applying these strategies in combination across a corridor in response to varying conditions is expected to reduce congestion "hot spots" in the system, and improve the overall productivity of the system. Furthermore, providing travelers with actionable information on alternatives (such as mode shift, time of travel shift, and/or route shift) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

The objectives of the ***"ICM – Tools, Strategies, and Deployment Support"*** project are to refine Analysis Modeling and Simulation (AMS) tools and strategies, assess Pioneer Site data capabilities, conduct AMS for three Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations. Efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites, and evaluating the expected benefits to be derived from implementing those ICM systems.

The overall benefits of this effort include the following:

- Help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion and improve safety; comprehensive modeling increases the likelihood of ICM success, and helps minimize unintended consequences of applying ICM strategies to a corridor.
- Help estimate the benefit resulting from ICM across different transportation modes and traffic control systems; without being able to predict the effects of ICM strategies corridor transportation agencies may not take the risk of making the institutional and operational changes needed to optimize corridor operations.

- Transfer knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

This ***AMS Analysis Plan for the Interstate 394 (I-394) Pioneer Corridor*** outlines the various tasks associated with the application of the ICM AMS tools to the corridor in support of a benefit/cost assessment of the proposed strategies. The following is the organization of this Analysis Plan:

- **Section 2** provides a brief description of the Pioneer Corridor in Minneapolis, Minnesota, and the methodology used for the AMS;
- **Section 3** lays out ICM strategies that will be tested, and provides a list of the AMS scenarios;
- **Section 4** defines performance measures that will be utilized in the analysis of the ICM strategies on the Pioneer Corridor;
- **Section 5** sets out the simulation model validation requirements and the data needs for this calibration;
- **Section 6** presents an overview of the Pioneer Corridor AMS document that will be developed to summarize the results of the AMS effort; and
- **Section 7** provides the schedule for the AMS tasks.

1.1 Principles in Developing and Applying the Analysis Plan

A number of principles apply in developing and applying the Analysis Plan. These are summarized as follows:

- **Resource and Schedule Constraint –** The overall ICM AMS effort must take place within the budget and schedule specified in the Analysis Plan. Data, models, and tools available at the Pioneer Site will be leveraged in the AMS effort.
- **Focus on Integration of Existing Tools –** The ICM AMS effort does not focus on developing new analytical tools; instead, it focuses on a relevant, meaningful application of **existing** modeling and simulation tools.
- **Recognize Current Limitations in Available Tools and Data –** There are known gaps in existing analysis tools that the AMS methodology must bridge. Examples of these gaps include the dynamic analysis of transit and mode shift, and the dynamic analysis of ICM strategies such as traveler information or congestion pricing. Bridging these gaps requires the interface of existing analysis tools with different capabilities.
- **Consistency of Analytical Approaches and Performance Measures –** ICM Pioneer Sites have different analysis tools at their disposal. The application of the AMS methodology to the various Pioneer Sites must be consistent in terms of analysis approach and performance measures. Consistency is important when trying to synthesize lessons learned in each site into national-level guidance.
- **Benefit/Cost Analysis –** Expected benefits resulting from the implementation of ICM strategies will be compared to expected costs to produce estimates of benefit/cost ratios and net benefits associated with the deployment of ICM strategies. This will help identify cost-effective ICM strategies, help differentiate between low- and high-payoff ICM strategies, and help prioritize ICM investments based on expected performance.

Chapter 2 I-394 Corridor Site and AMS Methodology

The I-394 Corridor is an east-west route connecting the Minneapolis Central Business District (CBD) with the western suburbs. This is a primarily commuter route as evidenced by the relatively low heavy-truck percentage of four percent, and the distinct directional peaks in congestion. The corridor's study area extends from the Minneapolis CBD to the Hennepin County border to the west, TH 55 to the north, TH 7 to the south, and Hennepin Avenue/7th Street to the east. Traffic on I-394 reaches 151,000 vehicles per day near the CBD.

In addition to I-394, the roadway network in the study area includes three north-south freeways, I-494, TH 169, and TH 100, as well as a number of arterials, including TH 7 and TH 55, which provide east-west alternative routes to I-394. Express and local buses run along the corridor with transit stations at Louisiana and Plymouth Avenues. Finally, I-394 provides direct access to the ABC garages (three garages totaling 6,755 spaces) located at the western edge of the CBD.

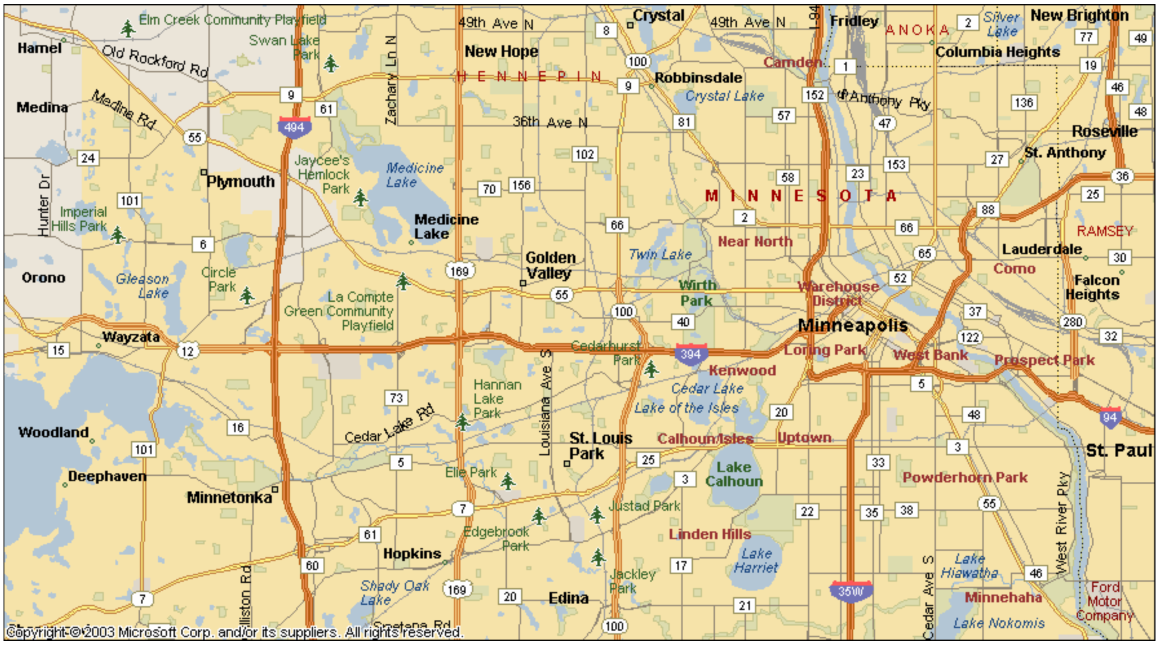
Figure 2-1 illustrates the Pioneer Corridor and the roadways included in the study area, while the following sections provide a detailed overview of the study corridor.[1]

2.1 I-394 Corridor Description

On May 16, 2005, the Minnesota Department of Transportation (Mn/DOT) started operation of the State's first application of high-occupancy toll (HOT) lanes on a segment of the I-394 corridor in the Minneapolis/St. Paul region. This system, known locally as MnPASS, represents the first deployment of HOT lane strategies in Minnesota and one of the first in the United States that dynamically adjusts pricing levels in response to varying traffic conditions.

[1] *I-394 MnPASS Technical Evaluation*, Cambridge Systematics, Inc., November 2006.

Figure 2-1. Location and Geographic Boundaries of Corridor



[Source: MnDOT.]

Unique within the Twin Cities region, I-394 also has two reversible, barrier-separated high-occupancy vehicle (HOV) lanes located in the center median between I-94 and TH 100. Historically, these lanes were open to buses and carpools only with two or more passengers in the inbound (eastbound) direction from 6:00 a.m. to 1:00 p.m., and open in the outbound (westbound) direction from 2:00 p.m. to midnight on weekdays. These lanes also were opened to buses and HOV traffic on a limited basis on weekends; usually in support of special event traffic. The lanes were closed at all other times. This portion of the I-394 HOV corridor is referenced as the "***reversible lane"*** section.

West of TH 100, the facility was built with a single, nonbarrier-separated HOV lane in each direction. Prior to the introduction of MnPASS, the HOV lanes were designated for use by carpools and transit vehicles during the morning commute period (6:00 a.m. to 9:00 a.m.) for the inbound direction, and during the afternoon commute period (3:00 p.m. to 6:00 p.m.) for the outbound direction. The HOV restrictions on this section of the corridor were only applied on weekdays, and the lane was available for use by all traffic for the remaining hours of the day. This portion of the I-394 HOV corridor is referenced as the "***diamond lane"*** section.

The I-394 freeway historically had been well utilized and often experienced congestion, particularly during the commute hours. While HOV demand in the corridor had been robust, it was often less than the available capacity, resulting in the perception among some residents that the HOV lanes were underutilized. As a result of this perception, Mn/DOT was directed by the Legislature in 2000 to evaluate various options for increasing the utilization of the HOV facilities, including opening the HOV lane to all vehicles and the conversion to an HOT lane operation.

The MnPASS system, made operational on May 16, 2005, allowed single-occupancy vehicles (SOV) to use the HOV (MnPASS) lanes by electing to pay a toll. The actual price of the toll (ranging from $0.25 to $8.00) varies with the current congestion levels and with the distance traveled – a different toll is paid whether the MnPASS subscriber chooses to travel on the reversible section, the diamond lane section, or both. The price of the toll is advertised through the use of Dynamic Message Signs (DMS) placed at strategic locations throughout the corridor, and the toll is paid electronically through a user-obtained transponder positioned within the vehicle.

All vehicles previously eligible to use the HOV lanes, including public transit vehicles, carpools, and motorcycles, are still able to use the MnPASS lanes free of charge; however, access and egress to and from the MnPASS lane in the diamond lane section are now limited to specific entry and exit merge areas. As originally developed and implemented, the MnPASS system was intended to operate 24 hours a day, 7 days a week (24/7); however, due to some residents' concerns regarding new restrictions on SOV use of the lanes during nonpeak hours and in the nonpeak direction, operational hours were modified to a slightly expanded approximation of the previous operational hours and direction of HOV lane restrictions. The current operational hours for the MnPASS lane in the diamond section are 6:00 a.m. to 10:00 a.m. for the inbound direction (an addition of 1 hour of morning commute period HOV restrictions compared with historical hours), and 2:00 p.m. to 7:00 p.m. for the outbound direction (an addition of 2 hours of afternoon commute period HOV restrictions compared with historical hours). These operational hour modifications were implemented approximately 1 month after the opening of the MnPASS system.

2.2 Modeling Approach

The modeling approach that emerged from the analysis of capabilities found in existing AMS tools, as well as from the ICM Test Corridor project, is an ***integrated platform that can support corridor management planning, design, and operations by combining the capabilities of existing tools***. The integrated approach is based on ***interfacing travel demand models, mesoscopic simulation models, and microscopic simulation models***. The Pioneer Corridor AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – may be utilized for evaluating ICM strategies.

The AMS methodology applies macroscopic trip table manipulation for the determination of overall trip patterns, mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes), and microscopic analysis of the impact of traffic control strategies at roadway junctions (such as arterial intersections or freeway interchanges.) The methodology also includes the development of interfaces between different tools, and the application of a performance measurement and benefit/cost module.

The paragraphs below provide an overview of the various modeling components anticipated to be utilized in the AMS modeling framework.

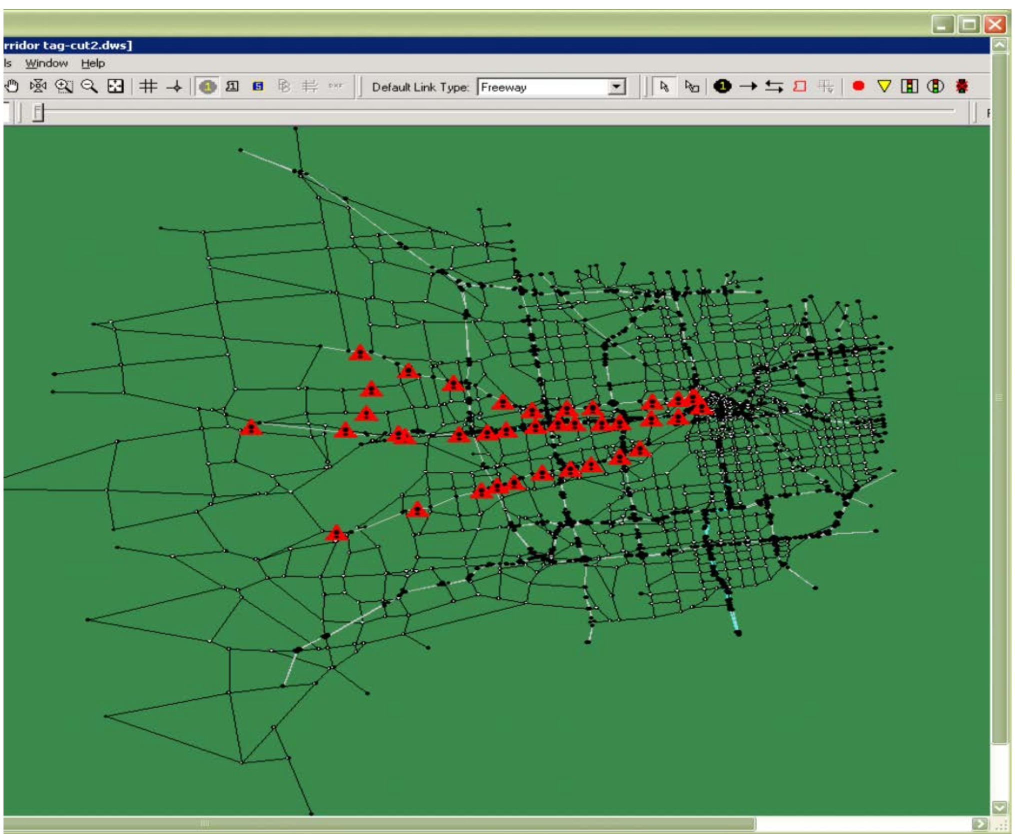
Travel Demand Forecasting Model

The Minneapolis Metropolitan Planning Organization (MPO) travel demand model is developed in TP+, and covers an area larger than the I-394 Corridor study area. Travel demand models estimate travel demand based on projections of household and employment characteristics, and predict travel preferences in activity location, time of day, mode, and route choice. The static nature of the travel demand models is not entirely compatible with the dynamic nature of travel choices during an incident situation. DynusT, the selected mesoscopic model for the I-394 corridor study area, models the diversion to different routes and/or to different modes during simulation run time, thus circumventing the need to feed back to the travel demand model and providing a more realistic view of the decisions and their impact to network condition. During the analysis of the I-35W bridge collapse, the University of Arizona migrated the MPO's travel demand model to DynusT and, therefore, no interaction with the travel demand model is planned.

Mesoscopic Simulation Model

Mesoscopic models combine properties of both microscopic and macroscopic simulation models. The mesoscopic models' unit of traffic flow is the individual vehicle, and the model assigns vehicle types and driver behavior. It also takes into account their relationships with the roadway characteristics. The movements in a mesoscopic model, however, follow the approach of macroscopic models and are generally governed by the average speed on the travel link. Mesoscopic models provide less fidelity than microsimulation tools, but are superior to travel demand models; in that, mesoscopic models can evaluate dynamic traveler diversions in large-scale networks. DynusT employs a more refined vehicle speed calculation based on the notion that a vehicle's prevailing speed is affected by vehicles in front and ahead of it, no matter if they are in the same lane or not. Furthermore, DynusT has the capability to perform "select link" analysis, in which the origins and destinations of the traffic traversing the main corridors (e.g., I-394, TH 55, TH 7, I-494) within the I-394 corridor study area are captured. Utilizing this feature, the limits/boundaries of the I-394 corridor study area were determined. Figure 2-2 illustrates the extracted subarea network for the ICM corridor.

Figure 2-2. I-394 Corridor Subarea Network

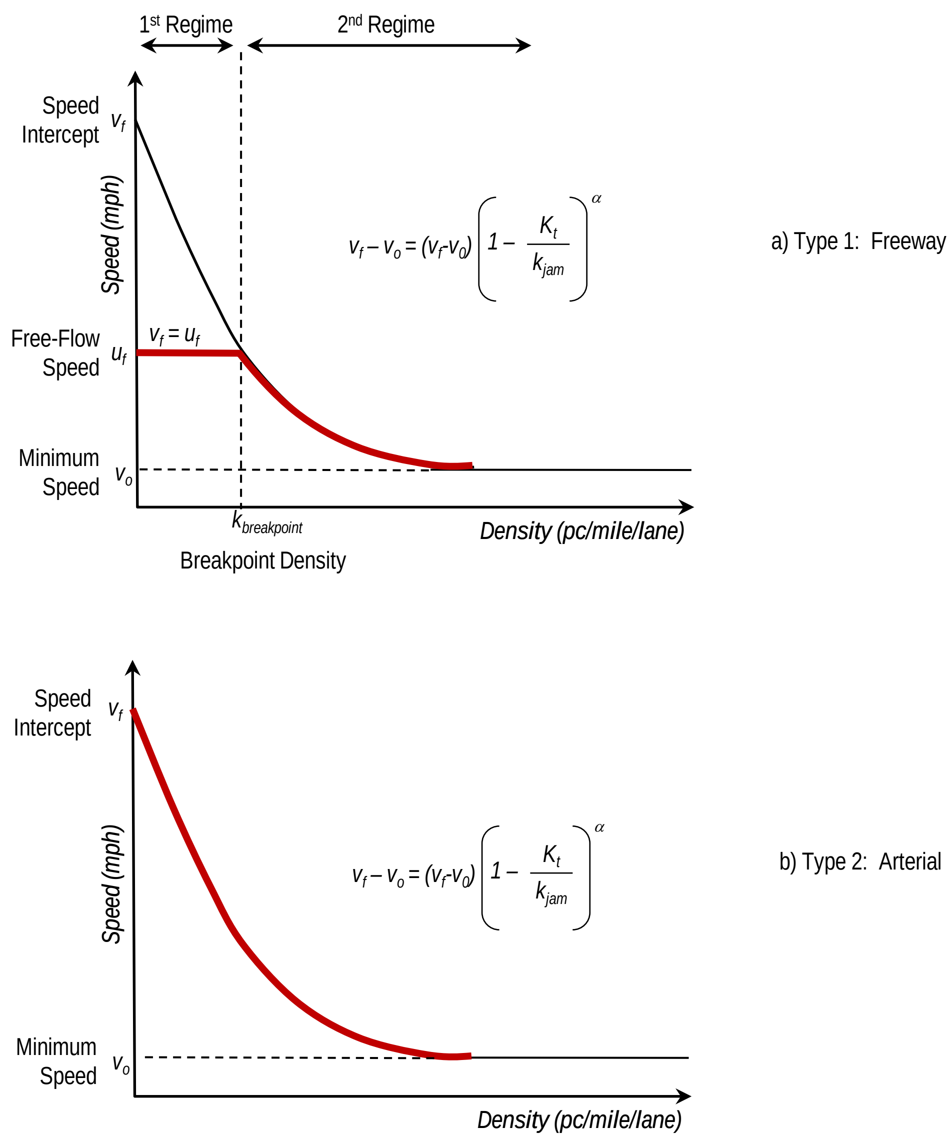


[Source: I Screen Capture DynusT software ©DynusT Lab.]

For the analysis of the I-394 corridor, the most recent version of DynusT will be used. The flow model utilized in DynusT is based on the modified Greenshields' model as shown in Equation 1, which follows the basic traffic engineering principles and relationships of speed, density, and flow. There are two types of traffic flow models identified in DynusT. Type 1 is better suited for freeway traffic flow, because freeway links have greater capacity than arterials, and can hold larger densities near free-flow speeds. Type 2 is better suited for interrupted flow roadways (arterials, ramps), reflecting their lower capacity and their sensitivity to density changes. Both flow model types are shown in Figure 2-3.

$$v_i - v_0 = \left(v_f - v_0\right)\left(1 - \frac{\kappa_1}{\kappa_{jam}}\right)^{\alpha} \qquad \text{(Equation 1)}$$

Figure 2-3. Modified Greenshields Model



[Source: University of Arizona.]

Free-flow speed v_f, minimum speed v_0, density breakpoint $k_{breakpoint}$, and jam $k_{breakpoint}$ density k_{jam} are estimated based on field data. The unknown variable α is the shape term that gives the curvature of the speed-density curve as the density increases.

DynusT is a User Equilibrium (UE) Dynamic Traffic Assignment (DTA) model incorporating algorithms that adjust the path assignment using an iterative solution procedure. The procedure is said to have converged, or reached an acceptable approximation to a UE solution, when there is no incentive for a user to shift paths (i.e., a traveler will not improve his/her travel time by selecting another alternate path). This translates to no significant changes in flow pattern, or experienced travel time {*XE "experienced travel time"*} after multiple iterations.

DynusT utilizes a convergence criterion based on path travel times, termed the *relative gap*, which also is a rather common stopping criterion used by static traffic assignment models. The typical definition of the total relative gap is:

$$rel_{gap} = \frac{\sum_t \sum_{i \in I} \sum_{\kappa \in K_i} f_\kappa^t \tau_\kappa^t - \sum_t \sum_{i \in I} d_i^t u_i^t}{\sum_t \sum_{i \in I} d_i^t u_i^t}$$

(Equation 2)

Where z is an index for an assignment interval {*XE "experienced travel time"*} or a departure time interval, i is an index for an origin-destination (O-D) pair, and k is an index for a path. Index i represents the set of O-D pairs, and k_i denotes the set of paths connecting the O-D pair i. f_κ^t represents the flow on path k, departing at assignment interval t, τ_κ^t is the travel time on path k for assignment interval t. $d_\kappa^t d_i^t$ denotes the demand (total flow) for O-D pair i at time interval t, and u_i^t is the shortest path travel time for O-D pair i and departure time interval t. For the I-394 corridor, the *relative gap* was set to 5 percent.

From a behavioral standpoint, routes resulting from a DUE application could be viewed as a representation of the travelers' established long-term routes (habitual paths). In contrast, routes resulting from an incremental assignment could be viewed as a representation of the travelers' routes resulting from pre-trip information about the optimal routes at the time of departure. During the simulation, if the travelers do not update their path en-trip, it is assumed they are invariably staying with the path given by the pre-trip information. They either do not have en-trip information or they choose not to divert regardless of the en-trip traffic condition. If the travelers update their path en-trip, it is assumed that they access en-trip information along the journey and are willing to consider diversion.

In reality, the traveler population is composed of a mix of the above route choice habitual behavior and traveler information accessibility and usage. In evaluating the scenarios, one needs to carefully specify adequate market share of different behavior classes. DynusT allows the modeler to specify percentage of travelers following the habitual paths or access pre-trip and/or en-trip information. In DynusT, there are five classes comprising the traveler population – habitual path, system optimal, user equilibrium, en-trip information, and pre-trip information. Furthermore, DynusT allows the modeler to assess either the short- or long-term impact of a scenario. The following paragraphs describe the proposed methodology for the scenarios and strategies to be modeled for the Minneapolis site.

1. **Baseline Scenario (Future scenario *without* Incident) –** Travelers will be generated from O-D matrices, with a certain percentage assumed to have access to pre-trip information (incremental assignment) and the remaining to follow habitual paths. DynusT will run to DUE and the vehicles and their associated paths will be saved. The vehicle file will contain all vehicle attributes, including user class ID, departure time, arrival time, etc.
2. **ICM Scenarios (Future scenarios *with* Incident) –** Travelers are loaded to the network through the vehicle file following a habitual path file. A certain percentage of travelers will be specified to access pre-trip information or en-trip information.

Microscopic Simulation Model

Microscopic simulation models simulate the movement of individual vehicles, based on theories of car following and lane changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process), and are tracked through the network over small time intervals (e.g., one second or fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, the traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation, based on relationships developed in prior research. The primary means of calibrating and validating microscopic simulation models is through the adjustment of driver sensitivity factors.

A number of CORSIM models are available for the metro area network, and there currently are two Aimsun models underway at the University of Minnesota; one for the corridor and one for the arterials. Given that they are not integrated and the ability of DynusT to reflect arterial signal re-timing, microsimulation runs will not be undertaken.

Analysis of Mode Shift and Transit

A known gap in the analysis of ICM relates to the performance and impacts of transit services. Mode shift in the Pioneer Corridor can be influenced by adverse traffic conditions (incidents or heavy demand), and by ICM strategies (such as traveler information systems). Modeling of mode shift requires input of transit travel times, which are calculated by network segment and at key decision points in the corridor. This can support comparison of network and modal alternatives, and facilitate the analysis of traveler shifts among different transportation modes.

For the I-394 corridor, the University of Arizona has developed a methodology within DynusT to account for mode shifts. One important element of the application is the consideration of distance from the destination, since traveler information could entice users of the corridor to change their mode. For example, travelers may take transit instead of their vehicle, if they receive the information before their departure from home. Alternatively, they may decide to park their car at the nearest park-and-ride lot and switch to transit, if they receive en-trip information of an incident. Finally, they may choose to continue driving if they receive en-trip information of an incident, and they are either close to their destination or driving to the nearest park-and-ride lot significantly increases their time.

The approach developed by the University of Arizona team can be summarized as follows:

1. Alternatives are represented by utility functions with three variables measured during simulation – travel time, fare, and accessibility. The travel time attribute applies to both

existing and alternate routes and is primarily assessed from experience (e.g., prior UE run), but it could account for available ATIS information.

2. Fare is represented as cent per mile for simplification purpose, but the methodology can accommodate more complicated fare structures.
3. The accessibility measure is measured by two attributes – distance to park-and-ride facility and distance to final destination. The distance to nearby park-and-ride facility can be determined by querying the shortest path algorithm that is regularly executed. In this case, the origin is the location of the vehicle (could be en-trip or pre-trip), and the destination is the park-and-ride facility. Similarly, the distance to the final destination can be calculated by querying the distance label from the shortest path for candidate locations.

Chapter 3 Analysis Scenarios and ICM Strategies

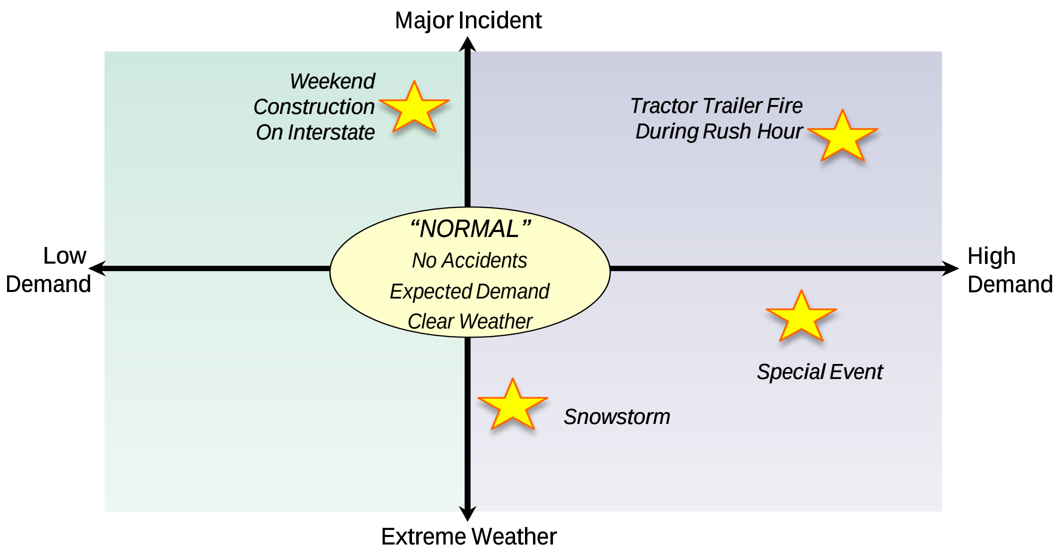
This section provides an overview of priority ICM strategies for this Pioneer Corridor, and the scenarios that will be studied to analyze the impacts of these strategies. The analysis will assist local agencies to:

- **Invest in the Right Strategies –** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with Confidence –** AMS will allow corridor managers to "see around the corner" and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.
- **Improve the Effectiveness/Success of Implementation –** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

3.1 Analysis Scenarios

The I-394 AMS Analysis Plan provides tools and procedures capable of supporting the analysis of both recurrent and nonrecurrent congestion scenarios. The Pioneer Corridor's nonrecurrent congestion scenarios entail combinations of increases of demand and decreases of capacity. Figure 3-1 depicts how key ICM impacts may be lost if only "normal" travel conditions are considered; the proposed scenarios take into account both average- and high-travel demand, with and without incidents. The relative frequency of nonrecurrent conditions also is important to estimate in this process – based on archived traffic conditions, as shown in Figure 3-2.

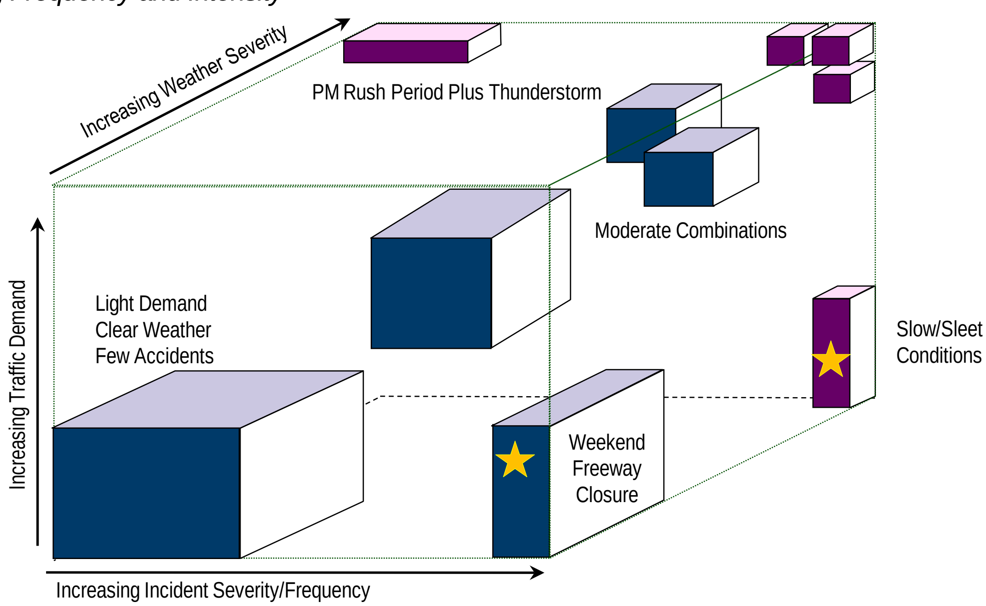
Figure 3-1. Key ICM Impacts May Be Lost If Only "Normal" Conditions Are Considered



[Source: Wunderlich, K., et al., Seattle 2020 Case Study, PRUEVIIN Methodology, Mitretek Systems. This document is available at the Federal highway Administration (FHWA) Electronic Data Library (http://www.itsdocs.fhwa.dot.gov/).]

Figure 3-2. Sources of System Variation

Classifying Frequency and Intensity

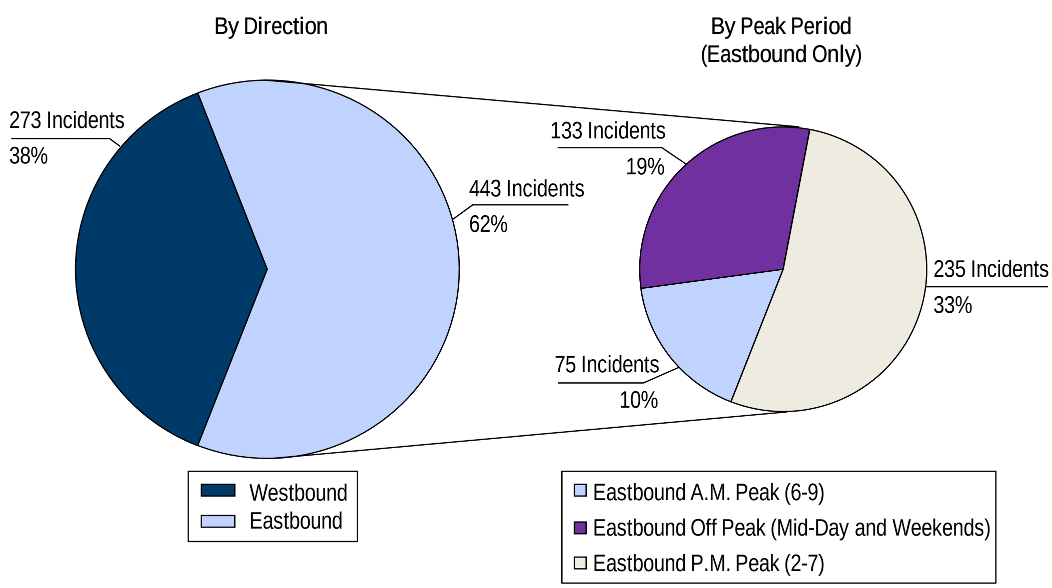


[Source: Wunderlich, K., et al., Seattle 2020 Case Study, PRUEVIIN Methodology, Mitretek Systems. This document is available at the FHWA Electronic Data Library (http://www.itsdocs.fhwa.dot.gov/).]

For the purposes of this study, a similar analysis was undertaken by Mn/DOT utilizing the incident data on the Twin Cities metro area freeways collected by the Minnesota Regional Transportation Management Center (RTMC). A five-year, from 2003 to 2007, data set was compiled and included freeway incidents that could potentially cause traffic delays, such as crashes, stalls, debris, vehicle fires, etc. For analysis purposes, incident data were limited to the hours of operation for RTMC staff (i.e., Monday through Friday, 6:00 a.m. to 8:30 p.m.; Saturday, 10:00 a.m. to 6:00 p.m.; and Sunday, 11:00 a.m. to 7:00 p.m.) and included all crashes and stalls that were blocking lanes for any period of time, since these types of incidents make up 34 percent of the total incidents on I-394 and have the greatest impact on congestion.

The first step in the analysis was to determine the directional split of incidents on I-394. As Figure 3-3 shows, 62 percent of all incidents occur in the eastbound direction, with most of these incidents being congestion-related, as the eastbound direction experiences significant congestion during both the AM and PM peak periods. Next, the frequency of incidents during the AM peak period (Monday to Friday, 6:00 a.m. to 9:00 a.m.); the PM peak period (Monday to Friday, 2:00 p.m. to 7:00 p.m.); and the off-peak period (midday and weekends) was determined. The analysis indicated that, on the average, 75 incidents occur during the AM peak period each year (roughly 10 percent of the total number of incidents on I-394 eastbound each year).

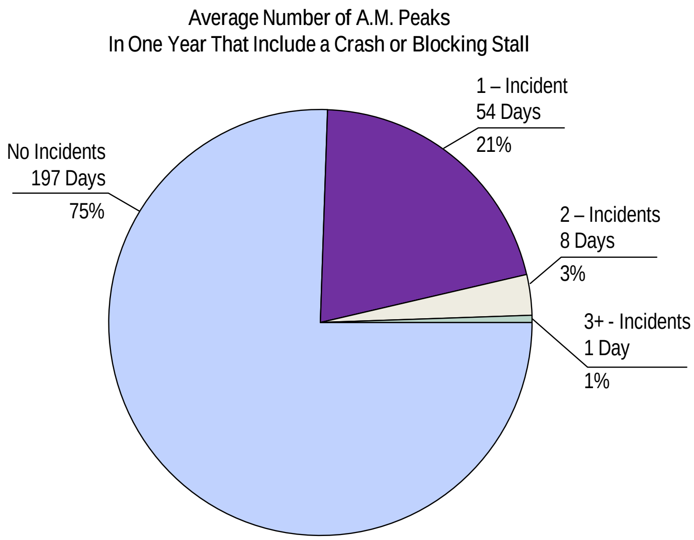
Figure 3-3. Classifying Incidents by Direction and Peak Period



Notes:
Average Annual Number of Crashes and Blocking Stalls on I-394
Data averaged over 5 years – 2003 to 2007
Data limited to RTMC Hours of Operations
M–F 5:30 am – 8:30 pm, Sat 10–6, Sun 11-7

Furthermore, as Figure 3-4 illustrates, 25 percent of all weekdays included at least one incident, which is defined as a crash or a blocking stall. The majority of weekdays, 75 percent, do not include this type of incident.

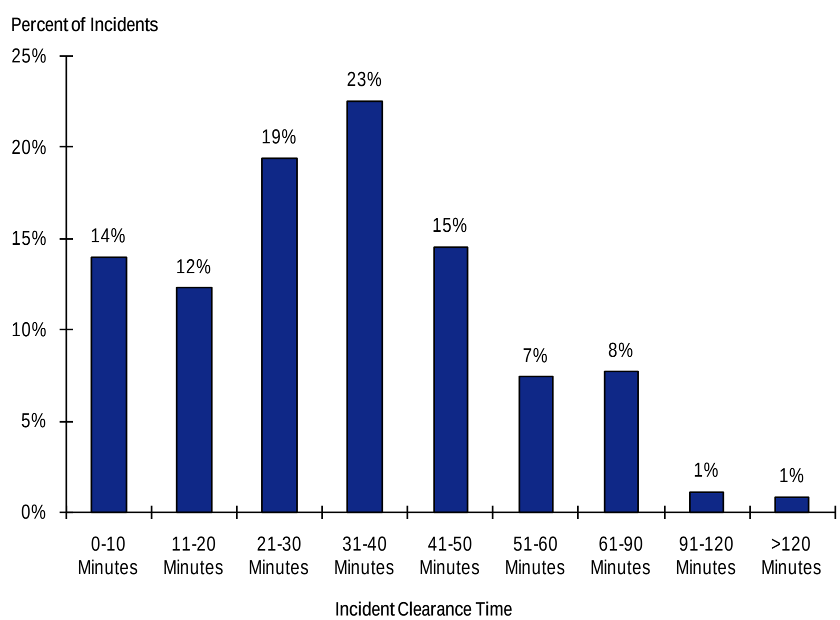
Figure 3-4. Incident Versus Nonincident Days (I-394 EB)



Notes:
Average Annual Number of A.M. Peak Incidents = 75 per year
Assumes 260 Weekdays in a Year

Figure 3-5 illustrates the frequency distribution of incident clearance time on I-394 eastbound for the AM peak period (6:00 a.m. to 9:00 a.m.). Incident clearance time was measured from the RTMC 2003 to 2007 incident logs, and is defined as the time from when an incident is detected to the time the incident clears the freeway. Based on the clearance times, any incident with clearance time less or equal to 60 minutes is considered a minor incident, while incidents with clearance times greater than 60 minutes are considered major.

Figure 3-5. Distribution of Incidents by Clearance Time *AM Peak Period*



Having identified the number of incidents that occur on I-394 eastbound during the AM peak period and their clearance time, the Minneapolis AMS team determined the joint frequency of incident clearance time and hourly demand. Hourly demand was calculated using entry ramp and upstream (western end of I-394) vehicle counts. Based on analysis and knowledge of the corridor, the Minneapolis AMS team concluded that the AM peak-period demand does not vary appreciably from day to day. The I-394 corridor is a heavily traveled commuter corridor during the morning peak hours, causing very little fluctuations in demand. During the afternoon peak period, the demand is more variable due to events at stadiums and entertainment venues at the east end of the corridor. Figure 3-6 illustrates the hourly demand by day of the week. Incident clusters were then identified based on similar clearance times and hourly demand volumes. Figure 3-7 illustrates the joint frequency distribution of incident clearance time and demand.

Figure 3-6. Variation of Weekday Hourly Demand (I-394 EB)

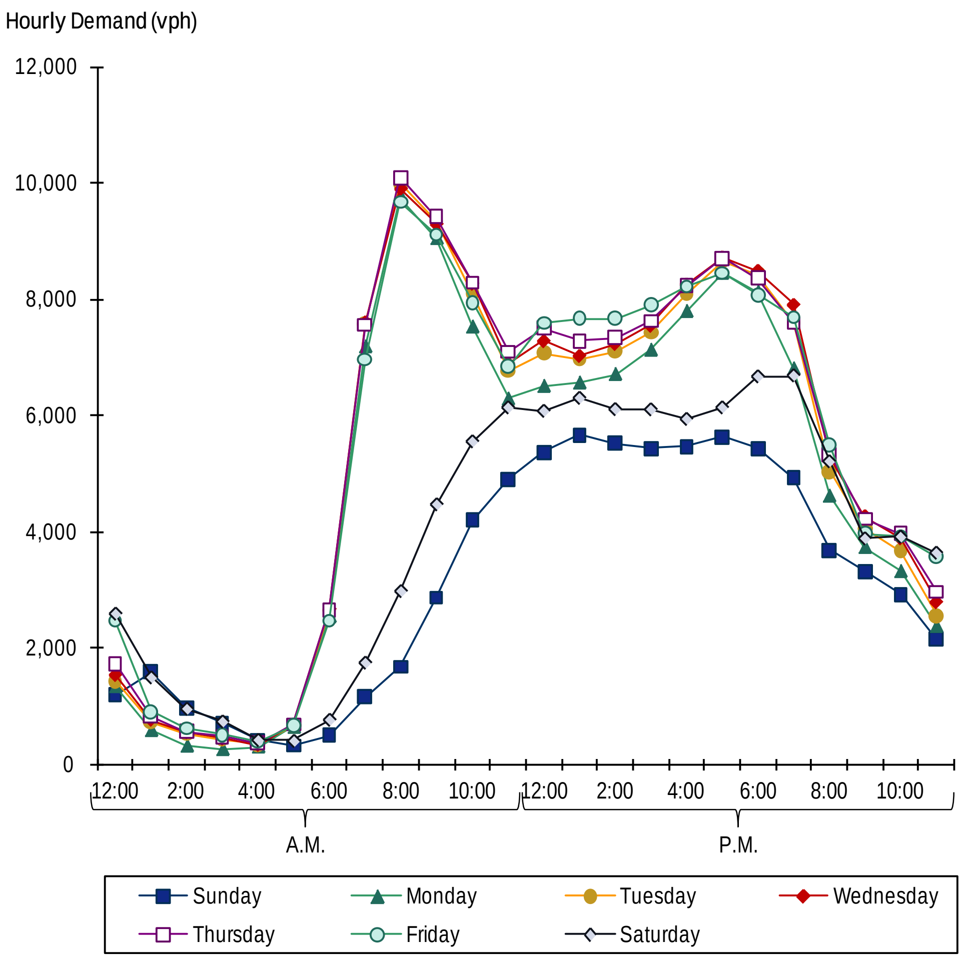
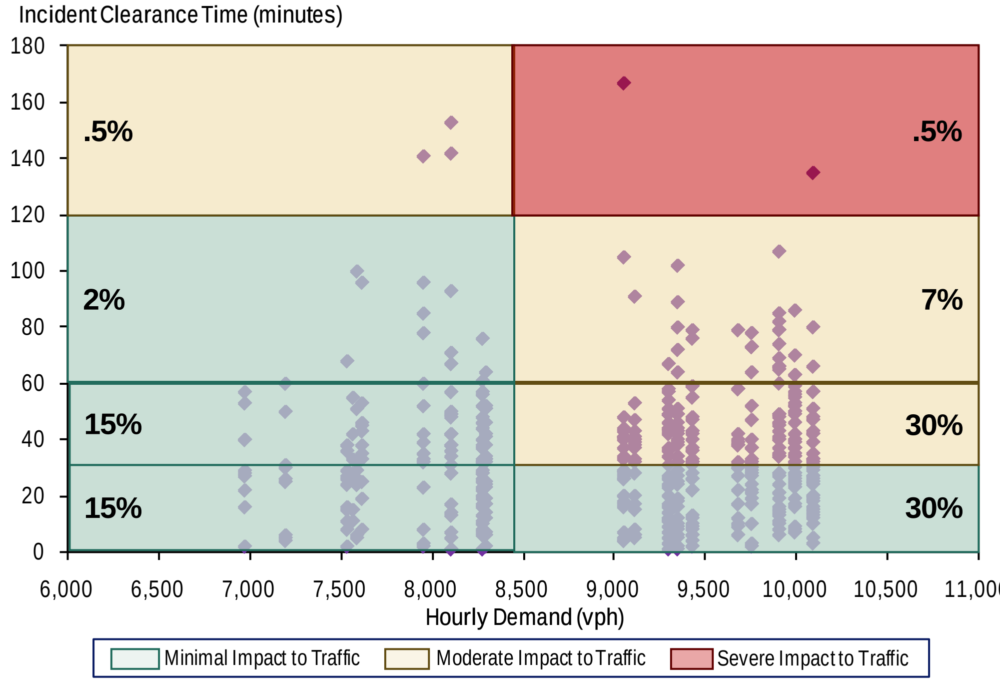


Figure 3-7. Distribution of Incidents by Clearance Time and Demand Level (I-394 EB)



In addition to the cluster analysis above, the Minneapolis AMS team developed 10 scenarios that 'paint a picture' of the activities to be performed by each stakeholder, the ICM strategies employed, and the likely impacts that would be experienced by travelers. These scenarios depict incidents as well as special situations such as a baseball game and a snow event; and are fully described in the I-394 Concept of Operations (ConOps) report. Incident scenarios are described as major or minor based on the severity and the clearance time of the incident. For the purposes of this study, the Minneapolis AMS team ranked the ConOps scenarios from low to high importance, and the following scenarios were identified as priorities (with no particular order):

1. Major freeway traffic incident;
2. Major arterial traffic incident;
3. Minor freeway incident;
4. Minor arterial traffic incident;
5. Special event; and
6. Weather condition.

Weather events reflect situations where snow, ice, or heavy rain has caused travelers to alter their patterns; often choosing arterials over freeways in order to avoid inevitable congestion. Special events include sporting events at the baseball stadium, basketball stadium, and football stadium (all in close proximity to the termination of the corridor). While there are expected benefits from the ICM strategies during weather events, the Minneapolis AMS team did not anticipate that the selected strategies will have a major impact during weather events, when essentially all routes and modes of travel are slower due to the hazardous conditions. In addition, the AM inbound peak period is not conducive to modeling special event scenarios since the special events that attract large volumes of traffic are almost always in the evening or afternoon (with some rare exceptions). Furthermore, travel demand patterns during special events could be drastically different compared to normal weekday peak-period patterns. Therefore, it was decided that the special event and weather scenarios be removed from further consideration so that available resources could focus on the scenarios where the ICM strategies may have the most impact.

One of the key objectives of the ICM project is the assessment of the proposed strategies under different operating scenarios; and in that regard, the cluster analysis, along with the I-394 ConOps report, provides the necessary assumptions. A key variable in defining an operating scenario is the pertinent demand level. Since the between-days demand variability for the I-394 corridor is not appreciable (as illustrated in Figure 3-6), it was decided to vary the incident starting time and benefit from the within-day demand variability. Based on Figure 3-6, the demand levels identified in the cluster analysis could be approximated with the following timeframe: the demand is estimated at 7,000 vph at 7:00 a.m.; 8,000 vph at 7:30 a.m.; 9,000 vph at 7:45 a.m.; and 10,000 vph at 8:15 a.m.

Furthermore, the propensity of each operating scenario will weigh in the effectiveness of a particular strategy; therefore, each operating condition is associated with a probability. The probabilities are calculated based on Figures 3-4 and 3-7. For example, the probability of not having an incident is 75 percent (see Figure 3-4), while the probability of an incident with an 80-minute clearance time is 25 percent (probability of an incident) times 2 percent (probability of an incident with 80 minutes clearance and hourly demand less than 8,500 vehicles – see Figure 3-7).

The Minneapolis AMS team developed a matrix identifying the freeway operating scenarios to be modeled, and they are summarized in Table 3-1, along with their characteristics. Since there will be no incident scenarios with clearance times of 120 minutes or more, the sum of the freeway operating scenario probabilities is 99.75 percent. A total of six freeway incident operating scenarios, as defined by severity, clearance time, and start time, have been identified along with the daily operations scenario.

Although complete incident log data for TH 55 and TH 7 are not available, there is data available that provides the number of crashes on each corridor. Data on the number of stalled vehicles and the duration of the incident is not available. Mn/DOT analysts collected crash data from the Department of Public Safety's crash report database during the 2003 to 2007 five-year period. This analysis found that 59 percent of all crashes occurred on I-394, while 41 percent of the crashes occurred either on TH 55 or TH 7. Therefore, it was decided, in addition to the I-394 incidents, to analyze one major arterial incident, simulated at a central location of one of the parallel arterials to I-394. The incident will reflect a closure of an arterial segment. Since there is no information regarding the probability of an arterial incident, for simplicity and practicality, we will assume that the probability for an arterial incident is 0.25 percent; the balance of the freeway incident probabilities. Therefore, the freeway and arterial incidents analyzed will represent 100 percent of the anticipated operating conditions in the corridor.

The number of runs identified in Table 3-1, reflect runs for each strategy (see Table 3-4) under a scenario as well as a run for the combination of strategies for each scenario. For example, for the scenario Freeway Segment Closed eight runs will be performed; one for each of the seven strategies (the HOT lane-congestion pricing strategy is part of the base scenario) and one for the combination of strategies. This analysis will allow for a comparison of strategies across incident severity and clearance time. Therefore, for the last two scenarios only the combined strategy runs will be performed.

Table 3-1. Freeway Operating Scenarios

Scenario	AM Peak-Period Daily Operations No Incident	Freeway Segment Closed	One Freeway General Purpose and Auxiliary Lane Blocked				
Incident Clearance Time (Minutes)		**80**	**80**	**30**	**45**	**30**	**45**
Severity		Major	Major	Minor	Minor	Minor	Minor
Location: I-394 Eastbound at Louisiana		●	●	●	●	●	●
Incident Start Time	N/A	8:00 a.m.	7:30 a.m.	7:15 a.m.	7:30 a.m.	7:45 a.m.	8:15 a.m.
Probability (Percent)	75	1.75	0.5	3.75	3.75	7.5	7.5
Number of Runs	1	8	8	4	4	1	1

3.2 ICM Strategies

Travelers have multiple possible responses to congestion and mitigating ICM strategies, such as route diversion, temporal diversion, mode change, and destination change or trip cancellation. The I-394 corridor will have a number of ICM strategies in operation in the near future, and the Analysis Plan takes that into account. The base year for analysis reflects 2008 travel demand to capture the operations of MnPASS. The Future Baseline scenario will be modeled using information for year 2011, which is the anticipated year of implementation. The ensuing sections provide details of the following strategies proposed by the Minneapolis AMS team:

- Earlier Dissemination of Traveler Information;
- Comparative Travel Times;
- Parking Availability at Park-and-Ride Lots;
- Incident Signal Retiming Plans;
- Predefined Freeway Closure Points;
- HOT Lanes;
- Dynamic Rerouting; and
- Transit Signal Priority.

Earlier Dissemination (Pre-Trip Traveler Information)

Earlier dissemination includes any travel information accessible to the public that can be used in planning trip routes, estimating departure times, and/or choosing travel modes. Such information can be available through the 511 system, public access television (TV), and other media. Annually since 1987, Mn/DOT has sought public opinion about transportation through a Transportation Omnibus survey. The last report was completed in 2006, and is now on a biannual schedule. Within the survey, there are questions related to the value of traveler information provided, and how motorists typically receive their information. Below is a sample question from the survey, while Table 3-2 provides a sample summary of the responses.

Think now about the different WAYS that you can access TRAVELER information. I am going to read a list of some SPECIFIC traveler information services, some that Mn/DOT offers and some that others offer. For each, please tell me if you have used it IN THE PAST YEAR.

Table 3-2. Sample Summary Responses From the Omnibus Survey

	Statewide			Metro			Greater Minnesota		
Means of Access[a]	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**
Regular TV	72%*	72%	66%*	72%*	72%	65%*	72%	74%	67%
Net – Radio	73%*	71%	68%*	71%	73%	70%	75%*	70%	67%*
General Radio	70%*	68%	65%*	66%	69%	66%	75%*	68%	65%*
KBEM Radio (88.5 FM)	11%	11%	12%	17%	14%	17%	5%	8%	6%
Net – Signs	74%*	71%	68%*	83%*	79%	75%*	66%	63%	62%
Electronic Freeway Message Signs	58%*	52%	50%*	71%*	66%	61%*	44%	38%	40%
Other Types of Road Signs	50%	47%	49%	51%	47%	51%	48%	48%	46%
Net – Web Sites	38%*	43%	45%*	40%*	47%	49%*	36%	39%	42%
Minnesota/DOT Web Site	15%*	19%	20%*	14%*	24%	22%*	15%	14%	17%
Other Web Sites	29%	33%	34%	32%	33%	35%	27%	33%	32%
511 Telephone Number	8%	7%	7%	5%	3%	4%	12%	11%	10%
Newspaper	28%	27%	26%	30%	27%	26%	26%	26%	27%
Other Types of Traveler Information	15%	13%	16%	15%	14%	17%	14%	12%	15%
Base	*800*	*800*	*800*	*400*	*400*	*400*	*400*	*400*	*400*

[a] Multiple responses were possible.

Other web sites (n=268) include: MapQuest 37 percent, Weather channel/weather.com 11 percent, Yahoo 8 percent,
Channel 4/WCCO 6 percent, Google 6 percent.

Other types of traveler information (n=125) include: AAA 21 percent, maps/road maps/atlas 16 percent, word of mouth 14 percent, telephone/cell phone 8 percent, GPS/navigation in vehicle 5 percent, friend/relatives 5 percent.

* indicates significant difference 95%=5%.

In addition to the Omnibus survey, the Minneapolis AMS team has available the Perception Tracking survey. The survey measures and compares traffic management tools, based on a sample of 600 interviews conducted over the telephone to individuals that drive and/or commute. The first survey was undertaken in 1996 and the latest in 2005. The following are some of the key findings of the 2005 survey:

- Traffic Internet awareness and use were 61 and 15 percent, respectively;

- 511 awareness and use were 30 and 4 percent, respectively;
- KBEM radio awareness and use were 50 and 9 percent, respectively;
- The proportion of drivers that had seen a travel time sign was 72 percent; and
- The proportion of drivers that used an alternate route, based on the travel time sign information, was 29 percent.

With travel times available on the 511 telephone system (including freeway, arterials, and transit), it is anticipated that the 511 telephone system will become a more valuable tool for commuters (now that 511 telephone is limited to incidents). Furthermore, with the push technologies planned (e-mail, text) travelers will be alerted to incidents and serious delays earlier than previously. The anticipated increased use of 511, combined with the planned e-mail and text alerts (travelers who do not turn on and log in to their computer could receive text messages to their telephones and be informed about conditions) is expected to increase the number of travelers utilizing available information in the future.

Based on the available data, the Minneapolis AMS team will utilize a pre-trip Traveler Information awareness and use of 61 and 15 percent, respectively, for modeling the operating scenarios for pre- and post-ICM. In addition, recognizing the potential ascending trend, the Minneapolis AMS team will examine a wider market penetration (use) of 20 and 25 percent for post-ICM.

Earlier Dissemination (En-Trip Traveler Information)

Discussions with U.S. DOT and Mn/DOT have revealed that there is a need to model the impact of en-trip information available to drivers to assess two major issues.

1. **Change in Route Choice –** This relates to real-time change in route choice of drivers based on travel time or congestion updates they receive via radio, or personal digital assistant (PDA)/global positioning system (GPS) devices. Based on the Perception Tracking survey, 72 percent of the drivers have seen a Travel Time Sign, but only 29 percent alter their route based on the available information. The Minneapolis AMS team believes that the addition of new Dynamic Signs, as well as the enhanced information these sign (current signs provide information for two points ahead in the pertinent corridor, while in the future, information also will be provided for alternate routes.), will increase both the percent of drivers that is aware of en-trip traveler information, and the percent of drivers that alter their route based on the available information (compliance ratio). Since there is no information related to other en-trip traveler information media (e.g., radio, GPS, etc.), the Minneapolis AMS team will utilize an en-trip awareness and compliance ratio of 72 and 29 percent, respectively, for modeling the operating scenarios for post- and pre-ICM. In addition, recognizing the potential ascending trend, the Minneapolis team will examine a wider market penetration of 90 percent, and compliance ratios of 35 and 50 percent for post-ICM.
2. **Change in Mode En-Trip –** The two transit stations (Louisiana and Plymouth Avenues) and the multiple park-and-ride lots at various locations along I-394 present limited, but potential, opportunities for changing mode while en-trip. Currently, travelers do not have access to comparable mode travel time or parking lot space availability information. This is expected to change, and the Minneapolis AMS team anticipates the traveler awareness to be raised from 0 percent today to 90 percent in the future. The percent of travelers that utilize this information will be evaluated utilizing the mode choice model integrated with DynusT.

Comparative Travel Times (Mode and Route)

Information dissemination (pre-trip and en-trip) will include travel time comparisons for freeway, arterial, and transit. As a result, it is anticipated that more travelers will choose the best option (alter route, mode, and departure time) to maintain consistent trip times.

Parking Availability at Park-and-Ride Lots

By disseminating information regarding park-and-ride lot availability, travelers' confidence in transit is expected to increase, and potential modal shifts during incidents may occur. Parking availability is incorporated as a variable within the mode choice model. Currently, three park-and-ride lots (Louisiana Avenue, Plymouth Avenue, and County Road 73) are considered for space monitoring.

Incident Signal Retiming Plans

Mn/DOT, City of Minneapolis, and Hennepin County are developing "flush" signal timing plans to decrease arterial travel time during an incident. The revised signal timings will be incorporated directly to DynusT.

Predefined Freeway and Arterial Closure Points

Using pre-designated freeway and major arterial closure points at intersections with freeways or major roads will avoid travelers being forced to exit at the last available exit point and enter a local road, causing more delay. The effects will be less delay to travelers forced to exit at closures, and less congestion on local arterials.

HOT Lanes

The I-394 ICM corridor includes an HOT facility along the I-394 freeway. The I-394 HOT facility allows HOVs with two passengers or more, including transit vehicles, to use the dedicated lane at no cost. The HOT facility also allows SOVs to use the lane by paying a toll. The price that SOVs pay varies according to the congestion level in the HOT lane. As part of the modeling effort, the Minneapolis AMS team will replicate the pricing strategy within the model to reflect the effect of the HOT charges on vehicle travel.

In addition, the ICM strategies include an option to open the HOT lane to all traffic during major incidents. While the intent of the HOT lane is to maintain free-flow conditions for HOV and transit vehicles, there are some situations along I-394 that merit opening the HOT lane to all traffic to allow a 'flush' of the vehicles. The decision to open the HOT lane to all vehicles would be based upon the location, severity, and duration of the incident. Opening the HOT lane to all vehicles is anticipated to be used in the following situations:

- If an incident is blocking multiple lanes of I-394, it may not be safe for travel to use any (or only one) of the general purpose lanes. This would essentially prevent any travel unless the HOT lane was open to all travelers.
- If an incident is causing congestion at a level where some HOV and transit vehicles were essentially stuck in the gridlock and could not reach the HOT lane, opening the HOT lane to all traffic might help to flush the traffic and free up the transit and HOV vehicles, therefore, benefiting everyone.

- If an incident is so severe and long lasting that the RTMC manager makes a judgment call that it is in the best interest of all travelers to open the HOT lane to all traffic.

During times when the HOT lane is open to all traffic, no vehicles will be charged for the use of the lane.

Dynamic Rerouting

Dynamic rerouting will reroute buses so that bus travel times remain consistent. This strategy will be reflected in the DynusT model with the use of alternate fixed routes.

Transit Signal Priority

A key objective of this ICM strategy is to improve transit efficiency and service by giving priority to buses leaving park-and-ride lots to return to I-394. This strategy will reduce the amount of time associated with the bus service, and potentially increase transit usage.

Table 3-3 cross-tabulates the scenarios and strategies, while Appendix A provides additional details reflecting pre- and post-ICM implementation, as well as expected model outputs.

Table 3-3. ICM Strategies and Scenarios Summary

Strategy/Scenario	Daily Operations No Incident	Freeway Segment Closed	One Freeway General Purpose and Auxiliary Lane Blocked			Arterial Segment Closed
Incident Clearance Time (Minutes)		80	80	30	45	65
Incident Severity		Major	Major	Minor	Minor	Major
Traveler Information						
Earlier Dissemination	●	●	●	●	●	●
Comparative Travel Times (Mode and Route)	●	●	●	●	●	●
Parking Availability at Park-and-Ride Lots	●	●	●	●	●	●
Traffic/Incident Management						
Incident Signal Retiming Plans for Arterials		●	●			●
Predefined Freeway Closure Points		●				
HOT/HOV Lanes						
HOT Lane (Congestion Pricing)	●	●	●	●	●	●
HOT Lane Open to All Traffic			●			
Transit Management						
Dynamic Rerouting		●	●			●
Transit Signal Priority	●	●	●			

Notes: Transit signal priority will be available at all times. Transit vehicles operating behind schedule will activate priority request signals. Once transit vehicles are no longer behind schedule, they will no longer emit priority request signals. TSP operation will not be tied directly to incidents; however, TSP is expected to assist primarily during major incidents that may cause delays to buses.
Freeway scenarios with the same incident severity and duration, but different start times, (see Table 3-1) are reflected once in the above table.
The HOT lane (congestion pricing) currently is in operation, thus is not considered an ICM strategy.

3.3 Summary of Analysis Settings

The number of ICM strategies and scenarios involved in the Analysis Plan makes it imperative to analyze only one peak period in order to stay within the schedule and resource constraints. Based on information provided in the ConOps document, I-394 eastbound experiences travel time variability in both the AM and PM peak periods. While the AM peak period experiences higher median travel times, the PM peak period experiences higher maximum times.

If only the PM peak were modeled, it would not be possible to model and analyze the strategies that specifically target modal shift, since commuters that have driven to work are not very likely to leave their vehicle at work and ride transit home. The only strategy that does not apply to the AM peak and would not be possible to model if only the AM peak is modeled is the ABC garage information dissemination (which is a strategy specifically targeting drivers of vehicles parked in the garage). Therefore, the Minneapolis AMS team believes that modeling the inbound direction during the AM peak period is the best option to receive the largest benefit of the model, since it will allow the modeling of transit decisions based on traveler information (as it is easier to influence modal choice when a commuter is traveling to work). Table 3-4 summarizes the anticipated analysis settings for the I-394 Corridor.

3.4 Data Requirements

The following is information of the data that will be utilized to finalize and implement the ICM strategies and scenarios:

- Freeway and arterial speed and volume data;
- DMS locations;
- HOT lane data (speed, volume, and price);
- HOT pricing updating rules or logics;
- Ramp metering data (ramp metering logic);
- Signal timing plans for the arterial intersection in the defined ICM corridor;
- Locations where the signal preemption devices have been or will be installed;
- Transit data (lines, frequencies, stop or terminal locations, existing diversion plans if available, etc.);
- 511 system utility information;
- Transportation Omnibus survey;
- Perception Tracking survey; and
- I-394 web site utility information.

Table 3-4. Summary of Analysis Settings

Parameter	Value	Comment
Base Year	2008	• The analysis is on the available regional DynusT, adjusted to reflect counts collected in the fall of 2008.
Analysis Year	2011	• The analysis year corresponds with the anticipated implementation year.
Time Period of Analysis	AM	• The analysis of the AM peak period provides the most benefit in terms of assessing the proposed ICM strategies.
Simulation Period	6:30 hours	• 5:00 a.m. to 11:30 a.m.; peak period 6:45 a.m. to 8:45 a.m.
Freeway Incident Location	Louisiana Avenue	• Based on Mn/DOT analysis this location experiences high number of incidents. In contrast with other high incident locations further East, this location also offer the potential for route diversions.
Arterial Incident Location	TBD	• Either on TH 55 or TH 7.
Incident Duration	Start time and clearance time	• See Table 3-1 for details.
Number of Scenarios	8	• Six freeway incident and one no incident (see Table 3-1). • One arterial incident scenario (see Table 3-3)
Anticipated Number of Runs (Post-ICM)	52	• Twenty-five individual strategy runs (see incident scenarios in Table 3-3 for details). • Ten runs reflecting 20 and 25 percent use of pre-trip traveler information, on the freeway incident scenarios. • Ten runs reflecting a 90 percent awareness and a 35 and 50 percent compliance for en-trip traveler information, on the freeway scenarios. • Six combined strategy freeway and one arterial incident scenario runs. • One no-incident scenario (this is the same as the validation run with an increased demand to reflect anticipated growth from the base year and daily operations in place).
Anticipated Number of Runs (Pre-ICM)	7	• Six freeway and one arterial incident scenarios, each reflecting combination of strategies currently in place.

Chapter 4 Performance Measures

This section provides an overview of the performance measures that will be used in the evaluation of ICM strategies for the I-394 corridor. To be able to compare different investments within a corridor, a consistent set of performance measures will be applied. These performance measures will:

- Provide an understanding of traffic conditions in the study area;
- Demonstrate the ability of ICM strategies to improve corridor mobility, throughput, reliability, and safety based on current and future conditions; and
- Help prioritize individual investments or investment packages within the Pioneer Corridor for short- and long-term implementation.

In addition, the Minneapolis AMS team defined four overall goals during the Concept of Operations development. These goals, together with candidate performance measures, are summarized below. Appendix B provides a draft Mn/DOT memorandum with additional details.

Goal 1. Mobility and Reliability – The I-394 Corridor network of agencies, infrastructure, systems, and supporting personnel will work together to maintain mobility and reliability of travel on a corridor basis.

Performance Measure – Travel Time Reliability.

Goal 2. Corridor-wide Capacity Utilization – Any spare capacity throughout the I-394 corridor will be used to the maximum extent possible.

Performance Measure – Vehicle and Person Throughput.

Goal 3. Corridor Event and Incident Management – There will be only minor impacts of incidents on travel time throughout the corridor, both in the extent of impact and duration; and that incident management will preserve the safety of the travelers throughout the corridor.

Performance Measure – Incident Impacts on Delay.

Goal 4. Holistic Traveler Information Delivery – To provide travelers and transportation professionals with a 'holistic' view of the corridor and its operations through the delivery of timely, accurate, and reliable multimodal travel information and data exchange.

Performance Measure – Influence on Travelers Behavior.

Based on goals identified by the Minneapolis AMS team and the objectives of the U.S. DOT ICM project, a set of national performance measures (see Appendix C) will be developed to assess the various scenarios and strategies. While these measures are not defined to support the testing of site-specific hypotheses on ICM impacts, they could potentially be utilized to indirectly assess site-specific goals. For example, Goal 4 is associated with specific changes in drivers' behavior, which are not modeled by the AMS efforts. Nevertheless, Goal 4 could still be indirectly addressed through the national measures, since improving reliability (as defined by the Planning Index) could be viewed as an indicator of better dissemination of travel information.

The proposed performance measures will focus on the following four key areas:

1. **Mobility –** Describes how well the corridor moves people and freight;
2. **Reliability –** Captures the relative predictability of the public's travel time;
3. **Safety –** Captures the safety characteristics in the corridor, including crashes (fatality, injury, and property damage); and
4. **Emissions and Fuel Consumption –** Captures the impact on emissions and fuel consumption.

U.S. DOT, in collaboration with the Pioneer Sites and Cambridge Systematics, Inc., developed guidance for mobility and reliability performance measures utilizing outputs from simulation models. The following sections provide an overview of the areas the selected performance measures will address, while Appendix C provides the U.S. DOT guidance.

4.1 Mobility

Mobility describes how well the corridor moves people and freight, and the Minneapolis AMS team will utilize the following three performance measures to quantify mobility in the I-394 corridor:

1. **Travel Time –** This is defined as the average travel time of the system across all origins, destinations, scenarios, and modes. Travel times will be computed for the peak period. Calculation details are provided in Appendix D.
2. **Delay –** This can be broadly defined as travel time in excess of some subjective minimum travel time threshold. Often, discussions of delay focus solely on roadway-only travel, but delay for the ICM project explicitly includes multimodal corridor performance. Specifically, delay is identified at the O-D level by deriving a zero-delay threshold by mode. Calculation details are provided in Appendix D.
3. **Throughput –** While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In the ICM AMS effort, we use the term corridor throughput to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. Passenger-miles traveled (PMT), passenger-miles delivered (PMD), and passenger-trips delivered (PTD) will be used as the throughput performance measures. Calculation details are provided in Appendix D.

4.2 Reliability and Variability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how much mobility varies from day to day. For the I-394 corridor, travel time reliability/variability will be calculated using the simulation models by performing multiple model runs for all scenarios. The planning index will be used as a measure for reliability, while the travel time variance will be used as a measure of variability. Calculation details are provided in Appendix C.

4.3 Safety

To better estimate the safety benefits of the ICM strategies on the I-394 corridor, available local freeway crash rates should be utilized stratified by severity. While total crash rates are available from Mn/DOT, stratified by severity rates are not available. Therefore, it was decided to benefit from the information available in the FHWA's ITS Deployment Analysis System (IDAS) tool, and adapt it to the local rates. In IDAS, crash rates are stratified by fatal, injury, and property damage only (PDO) crashes; and are applied based on roadway vehicles-mile traveled (VMT). Different rates are available for freeway links versus arterial links, with greater crash risks for arterial roadways. In addition, rates for injury and PDO crashes increase in relation to increased congestion (as measured by volume to capacity ratio for the roadway section),[2] to account for the risk of a crash.

The IDAS total default rates were compared with local crash data compiled by the Minnesota DOT Office of Traffic, Safety and Technology. The overall default IDAS crash rate across all crash types equates to 1.21 crashes per million VMT, compared to a rate of 1.10 crashes per million VMT, as observed on Minnesota urban freeways during the years 2004 to 2006[3] (Minnesota is fortunate to experience one of the lower crash rates in the nation). This comparison indicates that the observed crash rate (for urban freeways) in Minnesota is 90.5 percent of the IDAS comparable rate. This factor, in conjunction with a Mn/DOT crash analysis,[4] was used to adjust the IDAS crash rates to reflect local conditions, yet maintain the predictive ability of the IDAS rates, to estimate changes in crashes based on changes in congestion levels.

The IDAS freeway fatality crash rate is 0.0066 crash per million. Applying the adjustment factor, the local freeway fatality crash rate is estimated at 0.0060 crashes per million VMT. The IDAS and adjusted local crash rates for injury crashes and PDO crashes are presented in Table 4-1.

To calculate the number of crashes, the hourly V/C ratio and VMT for the freeway links will be utilized. The V/C metric will be used in a look-up function to determine the appropriate crash rate to apply to each link; and this rate will be multiplied with the link VMT. The number of crashes (by severity) will be summed up for all links and all hour, and the analysis will result in an estimated number of crashes (by severity) occurring under each scenario.[5]

The number of crashes then will be multiplied with the probability associated with each individual scenario to estimate the predicted crashes pre- and post-ICM. The difference in the number of crashes then will be multiplied with a benefit value to monetize the impact for use in the benefit/cost analysis.

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[2] V/C = Hourly Link Volume/Hourly Link Operational Capacity.

[3] *Traffic Safety Fundamentals Handbook*, Minnesota DOT Office of Traffic, Safety and Technology, August 2008.

[4] An I-394 demand and crash analysis, prepared by Mn/DOT (January 2009), was also used in evaluating the appropriate adjustment factor.

[5] In many cases, the number of crashes will be less than one for a particular scenario (particularly in the case of fatality crashes). No rounding will occur, but instead, the portion of crashes will be used as a measure of crash risk.

Table 4-1. Injury and PDO Crash Rates

Crashes Per Million VMT

Volume over Capacity (V/C) Ratio	IDAS Freeway Injury Rates	Adjusted Local Freeway Injury Rates	IDAS Freeway PDO Rates	Adjusted Local Freeway PDO Rates
< 0.09	0.4763	0.4312	0.6171	0.5587
0.19	0.4763	0.4312	0.6171	0.5587
0.29	0.4763	0.4312	0.6171	0.5587
0.39	0.4763	0.4312	0.6171	0.5587
0.49	0.4763	0.4312	0.6171	0.5587
0.59	0.4763	0.4312	0.6171	0.5587
0.69	0.4763	0.4312	0.6171	0.5587
0.79	0.5318	0.4815	0.7183	0.6503
0.89	0.5318	0.4815	0.7183	0.6503
0.99	0.6770	0.6129	0.8365	0.7573
1.00	0.7060	0.6392	0.9192	0.8322

4.4 Emissions and Fuel Consumption

The I-394 Corridor AMS also will produce estimates of emissions and fuel consumption associated with the deployment of ICM strategies, based on the methodology applied in the Test Corridor AMS. The Test Corridor AMS utilized the IDAS methodology, which incorporates reference values to identify the emissions and fuel consumption rates based on variables such as facility type, vehicle mix, and travel speed. The emissions and fuel consumption rates will be based on currently available sources such as Mobile or California Air Resources Board EMFAC. Emissions will be computed by pollutant, mode, and facility type. Fuel consumption will be computed by fuel type, mode, and facility type.

4.5 Cost Estimation

For the identified ICM strategies, planning-level cost estimates will be prepared, including life-cycle costs (capital, operating, and maintenance costs). Costs will be expressed in terms of the net present value of various components and are defined as follows:

- **Capital Costs –** Includes up-front costs necessary to procure and install ITS equipment. These costs will be shown as a total (one-time) expenditure, and will include the capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs –** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do

not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs will be presented as annual estimates.

- **Annualized Costs –** Represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement; and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Pioneer Corridor ICM deployments.

The complexity of these deployments warrants that these cost figures be further segmented to ensure their usefulness. Within each of the capital, O&M, and annualized cost estimates, the costs are further disaggregated to show the infrastructure and incremental costs. These are defined as follows:

- Infrastructure Costs – Include the basic "backbone" infrastructure equipment necessary to enable the system. For example, in order to deploy a camera (closed-circuit television (CCTV)) surveillance system, certain infrastructure equipment must first be deployed at the traffic management center to support the roadside ITS elements. This may include costs, such as computer hardware/software, video monitors, and the labor to operate the system. Once this equipment is in place, however, multiple roadside elements may be integrated and linked to this backbone infrastructure without experiencing significant incremental costs (i.e., the equipment does not need to be redeployed every time a new camera is added to the system). These infrastructure costs typically include equipment and resources installed at the traffic management center, but may include some shared roadside elements as well.
- **Incremental Costs –** Include the costs necessary to add one additional roadside element to the deployment. For example, the incremental costs for the camera surveillance example include the costs of purchasing and installing one additional camera. Other deployments may include incremental costs for multiple units. For instance, an emergency vehicle signal priority system would include incremental unit costs for each additional intersection and for each additional emergency vehicle that would be equipped as part of the deployment.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Infrastructure costs would be incurred for any new technology deployment. Incremental costs would be multiplied with the appropriate unit (e.g., number of intersections equipped, number of ramps equipped, number of variable message sign locations, etc.); and added to the infrastructure costs to determine the total estimated cost of the deployment.

Chapter 5 Model Calibration

Accurate calibration is a necessary step for proper simulation modeling. Before modeling the ICM strategies, model calibration will ensure that base scenario represent reality, creating confidence in the scenario comparison. The following sections provide an overview of the process, criteria, and target values that will be utilized in the calibration/validation of the model. Detailed narrative descriptions as well as comparisons between observed and modeled data will be provided under a separate Model Calibration and Validation document.

5.1 Simulation Model Calibration

Each simulation software program has a set of user-adjustable parameters that enable the practitioner to calibrate the software to better match specific local conditions. These parameter adjustments are necessary because no simulation model can include all of the possible factors (both on- and off-street) that might affect capacity and traffic operations. The calibration process accounts for the impact of these “unmodeled” site-specific factors through the adjustment of the calibration parameters included in the software for this specific purpose. Therefore, model calibration involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Calibration improves the ability of the model to accurately reproduce local traffic conditions. The key issues in calibration are the following:

- Identification of necessary model calibration targets;
- Selection of the appropriate calibration parameter values to best match locally measured street, highway, freeway, and intersection capacities;
- Selection of the calibration parameter values that best reproduce current route choice patterns; and
- Validation of the overall model against overall system performance measures, such as travel time, delay, and queues.

5.2 Calibration Approach

Available data on bottleneck locations, traffic flows, and travel times will be used for calibrating the simulation model for the analysis of the Pioneer Corridor. The I-394 Corridor calibration strategy will be based on the following three-step strategy recommended in the FHWA Guidelines for Applying Traffic Microsimulation Modeling Software:[6]

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[6] Dowling, R., A. Skabardonis, and V. Alexiadis, *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, FHWA-HRT-04-040, Federal Highway Administration, July 2004.

1. **Capacity Calibration –** An initial calibration performed to identify the values for the capacity adjustment parameters that cause the model to best reproduce observed traffic capacities in the field. A global calibration is performed first, followed by link-specific fine-tuning.
2. **Route Choice Calibration –** The arterials parallel to the I-394 Corridor could be used for traffic diversions during an incident, thus making route choice calibration important. A second calibration process will be performed with the route choice parameters. A global calibration is performed first, followed by link-specific fine-tuning.
3. **System Performance Calibration –** Finally, the overall model estimates of system performance (travel times and queues) will be compared to the field measurements for travel times and queues. Fine-tuning adjustments are made to enable the model to better match the field measurements.

Validation Criteria

The validation criteria presented in Table 5-1 will be applied for the I-394 corridor simulation, subject to the budget and schedule constraints for the Pioneer Corridor AMS.

Table 5-1. Validation Criteria for the I-394 Corridor AMS

Validation Criteria and Measures	Validation Acceptance Targets
• Traffic flows within 15 percent of observed volumes for links with peak-period volumes greater than 2,000	• For 85 percent of cases for links with peak-period volumes greater than 2,000
• Sum of all link flows	• Within 5 percent of sum of all link counts
• Travel times within 15 percent	• >85 percent of cases
• Visual Audits Individual Link Speeds: Visually Acceptable Speed-Flow Relationship	• To analyst's satisfaction
• Visual Audits Bottlenecks: Visually Acceptable Queuing	• To analyst's satisfaction

5.3 Model Calibration Data Requirements

The model calibration methodology outlined in Sections 5.1 and 5.2 requires a diversified set of data, including the following:

- Traffic flows at individual links, as well as on screenlines across the arterial, freeway, and transit components of the ICM Corridor;
- Travel times along critical segments of the ICM Corridor freeway and arterial components;
- O-D surveys, if available, identifying travel patterns along the freeway and arterial components of the ICM corridor; and
- Queue observations along critical segments of the ICM corridor freeway and arterial components.

5.4 Model Sensitivity

After the mesoscopic model is calibrated/validated for the base year, the model will be utilized to replicate operating conditions under a known incident before the assessment of the ICM strategies proceeds. This exercise will allow the Minneapolis AMS team to test the sensitivity of the various model parameters in replicating the queue build-up and dissipation capabilities of the model during an incident, as well as the diversion of traffic. The outcome of this review may necessitate the adjustment of the calibrated parameters, thus an update of the validated model. The Minneapolis AMS mined the available incident databases to compile information and data on an incident along the I-394 corridor, which could be used as the basis for the sensitivity analysis. The characteristics of the known incident are provided in Table 5-2.

Table 5-2. Known Incident Characteristics for the I-394 Corridor AM

Item	Description
Location:	Eastbound I-394 at I-494 Crash occurred just east of the I-394/I-494 interchange Blocking the right most through lane of I-394 (one lane blocked)
Date:	September 9, 2008
Start Time:	7:13 a.m.
End Time:	8:03 a.m.
Time to Clear Lane:	36.3 minutes (vehicles are moved to the side, but response still at the scene)
All Clear Time:	49.3 minutes

Chapter 6 Documentation

The methodologies, tools, and results of the Pioneer Corridor will be documented in a report that will be organized as follows:

- **Section 1** will outline the principles guiding the development and application of ICM AMS;
- **Section 2** will present the AMS methodology, and will provide a summary of the Pioneer Corridor site;
- **Section 3** will present the structure for the Pioneer Corridor analysis approach, performance measures, how to take into account nonrecurrent congestion, and ICM strategies and analysis alternatives applied for the Pioneer Corridor AMS; and
- **Section 4** will present the Pioneer Corridor AMS results, as well as conclusions and lessons learned.

Chapter 7 Schedule and Allocation of Responsibilities

The activities identified in this Analysis Plan are envisioned to be completed within a 15-month time period. Table 7-1 presents the proposed schedule. The University of Arizona will implement the ramp metering and HOT lane algorithms, validate the DynusT model, and run the future scenarios. Cambridge Systematics, Inc. will review the microsimulation models to identify potential capacity values that could be implemented in the mesoscopic model, assist the University of Arizona in the calibration/validation of the mesoscopic model, assess the effectiveness of the various strategies by estimating the performance measures identified above, and finally document the results and processes.

Table 7-1. Project Schedule

Number	Stage 2 AMS Milestone	Completion Goal
1	Baseline Calibration/Validation	November 2009
2	Baseline Model Sensitivity	November 2009
3	Performance Measures Definition	May 2009
4	Initial Alternatives Analysis	February 2010
5	Preliminary Results	February 2010
6	Final Alternatives Analysis	April 2010
7	Preliminary Results Report	March 2010
8	Webinar – U.S. DOT	TBD
9	Final Report	June 2010

APPENDIX A. Mn/DOT Summary of Pre- and Post-ICM Strategies

Table A-1 below presents the assumptions and anticipated outcomes of the selected ICM strategies.

Table A-2. Minnesota ICM – Table Outlining Assumptions of Outcomes and Effects

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
1. Traveler Information				
1.1 Earlier Dissemination	• Because of quicker notification, pre-trip and en-trip traveler information systems will disseminate incident information earlier to travelers. The effect will be that more travelers will be able to alter routes, modes, and departure times sooner.	• Information disseminated 10 minutes after start of incident (on average). • Current rate of travelers estimated to defer their travel time or cancel trip is 3 percent (estimated 1.5 percent defer and 1.5 percent cancel trip).	• Information disseminated 2 minutes after start of incident (on average). • Use current rate of travelers estimated to defer their travel time or cancel trip is 3 percent (estimated 1.5 percent defer and 1.5 percent cancel trip), but apply sooner.	• Amount of traffic that spreads to other routes and modes (based on information of event). • Change in travel speeds, volumes, travel times, and reliability.
1.2 Comparative Travel Times (Mode and Route)	• Information dissemination (pre-trip and en-trip) will include travel time comparisons for freeway, arterial, and transit. The effect will be that more travelers will choose the best options (alter routes, modes, and departure times) to maintain consistent trip times.	• N/A	• Travel times available on 511, web, e-mail, DMS, e-mail push within 2 minutes from incident onset. Number of additional travelers estimated to defer their travel time or cancel trip is 2 percent (estimated 1 percent defer and 1 percent cancel trip).	• Percentage of vehicles that alter route with information about shortest travel times. • Change in travel speeds, volumes, travel times, and reliability.

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs Pre-ICM	 Post-ICM	Reference Values to be Determined by Models
1.3 Parking Availability at Park-and-Ride Lots	• By disseminating parking availability at park-and-ride lots, travelers will feel comfortable choosing transit and know where they can park their car when appropriate; this will encourage more modal shifts, and avoid travelers being frustrated by driving to a park-and-ride and finding no parking available, and perhaps not trying it again. The effect will be increased modal shifts during incidents or congestion.	• N/A	• Park-and-ride availability/capacity. • Percentage of vehicles that will not enter park-and-ride lots and search for unavailable spaces, wasting time before continuing on the freeway. Likely a small percentage. • Available to travelers on telephone and web.	• Percentage of commuters will switch to transit (based on information about parking availability). • Percentage of vehicles will not enter park-and-ride lots and search for spaces (unavailable), wasting time before continuing on the freeway. Change in travel speeds, volumes, travel times, and reliability.
2. Traffic and Incident Management				
2.1 Incident Signal Retiming Plans	• Mn/DOT, City of Minneapolis, and Hennepin County will develop 'flush' signal timing plans that are coordinated and allow progression through different jurisdictions. The effect will be reduced arterial travel times during incidents or special event situations.	• Sixty minutes to implement optimized timing plans.	• Ten minutes to implement optimized timing plans. • Mn/DOT guidance on proposed flush plan operation (changes in green time, cycle lengths, etc.). Will need to be carefully implemented as to not disrupt overall arterial network performance.	• Reduced delays on Hwy 55 and Hwy 7. • Higher arterial capacity. • Reduced demand on I-394. • Change in travel speeds, volumes, travel times, and reliability.

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
2.2 Predefined Freeway and Arterial Closure Points	• By using predesignated freeway and major arterial closure points at intersections with freeways or major roads, this will avoid travelers being forced to exit at the last available exit point and entering a local road that causes more delay. The effects will be less delays to travelers forced to exit at closures, and less congestion on local arterials.	• Thirty minutes to deploy closures. • Mn/DOT provided description of a roadway closure plan for the identified incident.	• Ten minutes to deploy planned closure points at nearest freeway interchange upstream of the incident. Avoids closures at local roads and vehicles being forced on to local roads. • Mn/DOT provided description of a proposed roadway closure plan for the identified incident.	• Reduced delays of vehicles forced to exit I-394 due to a closure (traveling freeways instead of local roads). • Reduced delays to local travelers on local roads due to I-394 rerouted traffic. • Change in travel speeds, volumes, travel times, and reliability.
3. HOT/HOV Lanes				
3.1 HOT Lanes	• Existing today; should be included in the modeling. Can be opened to all traffic during major incidents.	• Maintain HOT lanes during major incidents.	• Open HOT lanes to all traffic within 5 minutes of major incidents to maximize throughput.	• Increased throughput on I-394. • Reduced delays. • Change in travel speeds, volumes, travel times, and reliability.

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
4. Transit Management				
4.1 Dynamic Rerouting	• Transit agencies (using improved information about congestion and incidents) will reroute buses around congestion and keep buses on schedule, maintaining consistent bus travel times. The effect will be consistent bus travel times.	• Rerouting occurs within 60 minutes.	• Rerouting occurs within 10 minutes. • Need to define transit rerouting plans for the one or two situations we are testing.	• Transit vehicles reduce delays by taking alternate routes. • Because transit travel times are displayed to travelers, travelers may be more (or less) inclined to ride transit (depending upon whether transit is faster or slower).
4.2 Transit Signal Priority (TSP)	• TSP at I-394 intersections next to park-and-ride lots will give priority to buses leaving park-and-ride lots and returning to I-394 (Note: TSP is not proposed along all of the arterial network). The effect will be more consistent bus travel times.	• No TSP.	• TSP for transit vehicles behind schedule.	• May avoid wait times at red lights until the vehicles are back on schedule. • Complex modeling task requires the tracking of transit vehicle travel time and modification of traffic signal timing, if performance is not within expected parameters.

APPENDIX B. Mn/DOT Performance Measures

Appendix B presents the Minneapolis AMS team definition of Performance Measures.

Minnesota I-394 Integrated Corridor Management (ICM)

1. Definition of Performance Measures – Draft

1.1 Introduction

Performance measures are typically numerical (or statistical) measurements of the degree to which a goal or objective is being met. The ICM initiative will use performance measures and related measures of effectiveness during the AMS stage to predict the extent to which the goals of ICM will be accomplished, and to forecast the annual benefits of ICM on the corridor.

The Minnesota I-394 ICM initiative defined four overall goals during the ConOps development. These goals, together with candidate performance measures, are summarized below.

Goal 1. Mobility and Reliability – The I-394 Corridor network of agencies, infrastructure, systems, and supporting personnel will work together to maintain mobility and reliability of travel on a corridor basis.

Performance Measure – Travel Time Reliability.

Goal 2. Corridor-Wide Capacity Utilization. Any spare capacity throughout the I-394 Corridor will be used to the maximum extent possible.

Performance Measure – Vehicle and Person Throughput.

Goal 3. Corridor Event and Incident Management – There will be only minor impacts of incidents on travel time throughout the corridor; both in the extent of impact and duration; and that incident management will preserve the safety of the travelers throughout the corridor.

Performance Measure – Incident Impacts on Delay.

Goal 4. Holistic Traveler Information Delivery – To provide travelers and transportation professionals with a 'holistic' view of the corridor and its operations through the delivery of timely, accurate, and reliable multimodal travel information and data exchange.

Performance Measure – Influence on Travelers Behavior.

The remainder of this document identifies hypotheses and measures of effectiveness to be used to assess the performance measures mapped against each ICM goal. Section 6 presents a matrix summarizing the content of the document.

2. Performance Measure 1 – Vehicle and Person Throughput

Throughput of vehicles and people on the I-394 Corridor will be used to measure the impact ICM has on accomplishing Goal 2 (Corridor-Wide Capacity Utilization). The goal is to maintain a consistent flow of travelers throughout the corridor, even during periods experiencing incidents, special events, or excessive demand.

2.1 Anticipated Impacts of ICM on Throughput

As the volume of a freeway or arterial increases past the point at which congestion occurs, there is no longer stable flow and the volume (throughput) decreases as the density increases. As a result, the volume of traffic begins to queue up along the route, and will eventually dissipate over time. In these situations, the excess demand is preventing the capacity of the roadway from being fully utilized, and often there are parallel alternate routes/modes that are underutilized. The ICM strategies are expected to spread out demand across the entire corridor (modes and routes) in order to maintain a consistent throughput corridor-wide. Additional ICM strategies may increase capacity through traffic or transit management approaches.

2.2 Hypothesis of ICM Impact on Throughput

Deploying and operating ICM will maintain consistent corridor-wide throughput, and avoid throughput reductions during incidents or special events. Volumes on one route or mode may decrease, while volume on other routes or modes may increase until the incident clears.

2.3 Measures of Effectiveness of ICM Impact on Throughput

Throughput MOE #1 – Percent change in the loss of traveler throughput during incidents or special events.

Throughput MOE #2 – Percent change in the time to recovery of throughput reduction caused by incidents or special events.

2.4 Defining a Measurable Value for Throughput in the I-394 Corridor

For purposes of the ICM AMS Phase, throughput on the I-394 corridor will be defined as follows.

Throughput is the total number of travelers who have passed through the corridor.

- Throughput will be measured at cordon lines within the corridor to determine the number of travelers passing through the corridor. The cordon lines will be selected at locations that allow for the measurement of travelers at the midpoint of the corridor and at the termination of the corridor.
- For modeling of the AM peak period, volume data from the following locations will be used to measure throughput:
- I-394 – Eastbound at Penn and Louisiana Avenues;
- Hwy 55 – Eastbound at Meadow Lane (one mile from Penn Avenue) and Louisiana Avenue;
- Hwy 7 – Eastbound at Wooddale Avenue and Texas Avenue (3,000 feet from Louisiana Avenue);

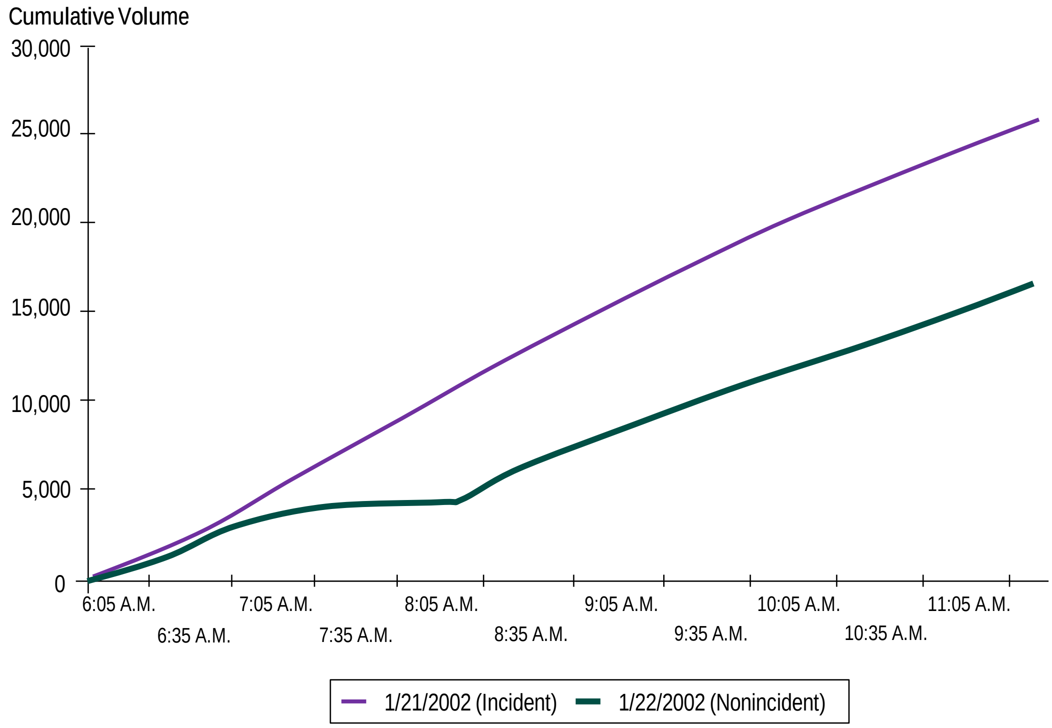
- I-494, Hwy 169, Hwy 100 – Northbound at a location north of Hwy 55;
- I-494, Hwy 169, Hwy 100 – Southbound at a location south of Hwy 7; and
- Transit ridership along routes through the corridor.
- Note: Throughput on the north/south routes are to be measured because there is considerable north/south traffic that uses this portion of the corridor simply as a pass through, and it is important to note the impacts of ICM strategies (positive or negative) on these trips.
- Figure B-1 below illustrates the estimated locations of cordon lines to be used to measure throughput.

Figure B-1. Candidate Locations of Corridor Throughput Measurements

[Source: MnDOT.]

- Total throughput will be the calculated for both the midpoint locations and the termination locations defined by the cordon lines, and will be computed by summing the volumes of passenger vehicles and transit riders. Occupancy values for each lane type are assumed as follows.
- I-394 – Multioccupant vehicles in the HOT lane = 2.1 persons per vehicle;
- I-394 – Tolled vehicles in the HOT lane = 1 person per vehicle;
- I-394 – General purpose lanes = 1 person per vehicle;
- Other freeways (I-494, Hwy 100, Hwy 169) = 1.1 persons per vehicle; and
- Arterials (Hwy 55, Hwy 7) = 1.1 persons per vehicle.
- Throughput reduction will be the decrease in travelers below the range of throughput measured during nonincident times.
- Figure B-2 illustrates the impact of an incident on throughput by plotting the cumulative volume (in vehicles) along I-394 eastbound at Penn Avenue for two consecutive days (one experiencing an incident and one not).

Figure B-2. Plot of Throughput Versus Time for Incident and Nonincident Conditions



2.5 Analyzing the Impacts of ICM on Throughput

Volume detector data and transit ridership data will be collected for a set of nonincident (typical) days at the locations identified above. Assumptions (identified above) on passengers per vehicle in both general purpose lanes and the HOT lane will be used to calculate a value for typical throughput for the I-394 corridor (transit and passenger vehicles). The throughput will be computed for 15-minute time slices between 6:00 a.m. and 9:00 a.m. The typical throughput will be a range of volume that represents 95 percent of nonincident travel days.

- A five-year, from 2003 to 2007, incident data set was compiled and included freeway incidents that could potentially cause traffic delays, such as crashes, stalls, debris, vehicle fires, etc. Figure B-3 illustrates the cluster analysis of that data set. The simulation model will be run to model the impacts of a subset of these incidents as selected based on the demand level and clearance time. Table B-1 summarizes the freeway incident scenarios to be analyzed.

Figure B-3. Distribution of Incidents by Clearance Time and Demand Level (I-394 EB)

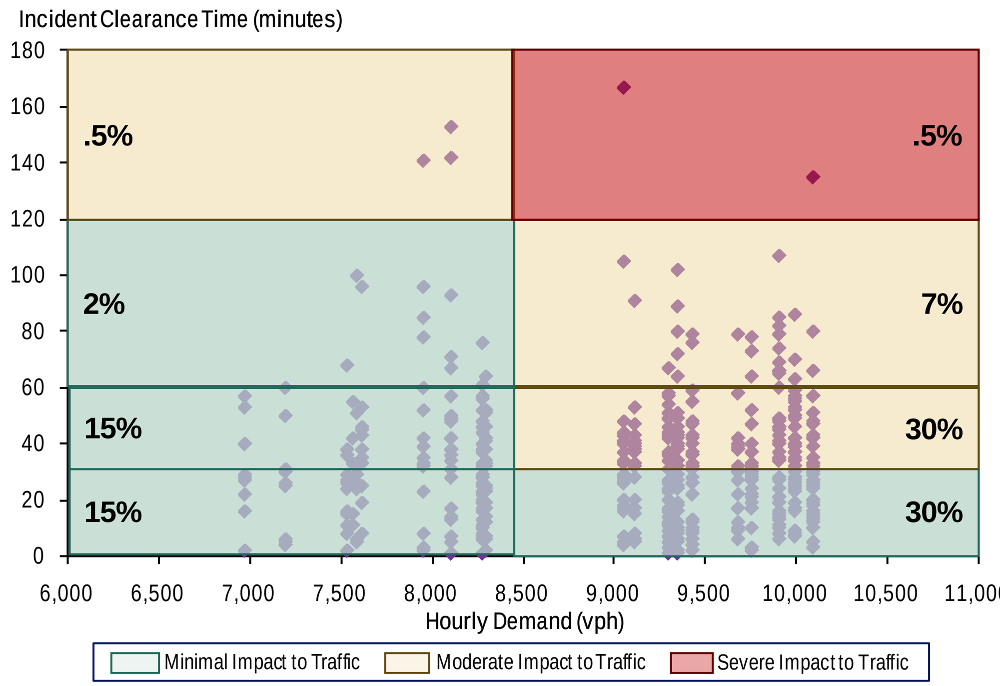


Table B-3. Freeway Incident Scenarios

Scenario	Freeway Segment Closed	One Freeway General Purpose and Auxiliary Lane Blocked				
Incident Clearance Time (Minutes)	**80**	**80**	**30**	**45**	**30**	**45**
Severity	Major	Major	Minor	Minor	Minor	Minor
Incident Start Time	8:00 a.m.	7:30 a.m.	7:15 a.m.	7:30 a.m.	7:45 a.m.	8:15 a.m.
Demand Level (VPH)	9,000-10,000	8,000	7,000-8,000	8,000	9,000	10,000

The actual circumstances of sample incidents will be used to direct the model runs. The model will be used to produce a total throughput for the corridor (sum of passenger volumes at the cordon points defined above) during each category of incident.

The model results will be used to compare the throughput in each 15-minute time slice during the incident (in the pre-ICM case) against the typical (nonincident) throughput.

- Mn/DOT's cluster analysis has identified the percentage of incidents that have been encountered in each of the demand and clearance categories, along with a number of days within a year. Therefore, any percent change in throughput, as a result of each category of incident, can be projected to an annual impact on throughput.

- The simulation model will be run again for each of the four incident categories for the post-ICM case. The model results will be used to compare the 15-minute time slices of throughput against the typical throughput. Any change in the impact of the incident on throughput will be understood to be the benefits of ICM.
- The results (when projected annually using the cluster analysis) will reveal the anticipated impact ICM has on maintaining a stable throughput during incidents and special events.

2.6 Data Needs and Availability

Table B-2 summarizes data collection requirements to calculate vehicle and person throughput, as well as the availability of data throughout the various stages of the ICM initiative.

Table B-4. Data Needs and Availability for Vehicle and Person Throughput

Data Collection Needed	Pre-ICM	Post-ICM	From Model
Freeways: Fwy (GP Lanes) – Volume Data Fwy (Tolled Vehicle) – Volume Fwy (HOV) – Volume	Yes	Yes	Yes
Arterial: Arterial – Volume Data	Partial (Fifteen-minute volumes; some historical data not available)	Yes	Yes
Transit Ridership	Partial	Yes	Yes

3. Performance Measure 2 – Incident Impacts on Delay

Measurements of the delay caused by incidents will be used to determine the impact ICM has on Goal 3: Corridor Event and Incident Management.

3.1 Anticipated Impacts of ICM on Delay

As incidents or special events reduce operational capacity along a roadway, or as travel demand exceeds the available capacity, the result is a reduction in speed, and, therefore, a delay to travelers. ICM strategies attempt to inform drivers about incidents and events in order to encourage alternate routes and modes. Other ICM strategies use traffic management and incident management approaches to increase capacity and maintain stable flow to the extent possible.

3.2 Hypothesis of ICM Impacts on Delay

The deployment and operation of ICM will reduce the frequency and extent to which travelers experience an increase beyond the normal levels of delay on the I-394 Corridor.

3.3 Measures of Effectiveness of ICM Impacts on Delay

Delay MOE #3 – Percent change in the annual increase in traveler hours of delay experienced by freeway and transit travelers during incidents and special events.
Delay MOE #4 – Percent change in the number of peak periods where freeway and transit travelers experience an increased delay of more than 10 percent.

3.4 Defining a Measurable Value for Delay in the I-394 Corridor

For purposes of the ICM AMS phase, delay caused by incidents on the I-394 corridor will be defined as follows:

- Delay will be defined as the total delayed passenger hours along the corridor.
- The incident impact on delay will be defined as the difference between typical delay and the delay encountered during an incident.
- Because of current limitations on real-time travel time information for arterials, delay will be calculated by determining the travel time through the corridor for freeway travelers and transit travelers, and multiplying the travel time by the number of travelers (throughput).
- In order to support a model analysis of the AM peak period, travel times will be computed for the following:
  - EB I-394 general purpose lanes (from I-494 to I-94);
  - EB I-394 HOT lanes (from I-494 to I-94); and
  - Transit travel times from park-and-ride facilities near I-494 to downtown.
- Travel times will be collected/modeled for 15-minute periods from 6:00 a.m. to 9:00 a.m. during nonincident (typical) days in order to determine typical travel times along all routes.
- Travel times will be collected/modeled for 15-minute periods from 6:00 a.m. to 9:00 a.m. during incident days to determine a comparable travel time.
- The incident impact on delay will be computed as (typical travel time – incident travel time) * number of travelers.
- The total incident impact on delay on the corridor will be computed as the sum of delay on the routes indicated above.

3.5 Analyzing the Impacts of ICM on Incident Influence on Delay

- Travel times will be measured for the designated routes, and the median travel time for each route/mode will be determined for each 15-minute increment from 6:00 a.m. to 9:00 a.m.
- The simulation model will be run to model the impacts of each of the four categories of incidents defined in the cluster analysis (using the actual circumstances of sample incidents to direct the model) for the pre-ICM case. The model will be used to produce individual travel times for each of the routes (median travel times determined for each 15-minute time period).
- For each route/mode, the difference between the travel time during incidents and the typical travel times will be computed. The result will be multiplied by the volume (throughput) occurring during the 15-minute time slice. This value will be the delay (person-hours of delay). The sum of all routes/modes will determine the total 15-minute incident impact on delay for the 15-minute time slice.

- The results of each 15-minute time slice can be summed to obtain the peak-period incident influence on delay (person-hours).
- Mn/DOT's cluster analysis has identified the percentage of days in a year that encounter each of the four categories of the incidents. Therefore, the calculated incident influence on delay will be multiplied by the number of days experiencing similar incidents to determine the annual impact of each category of incident.
- The simulation model will be run again for each of the four incident categories for the post-ICM case. The model results will be used to assess the total annual delay with ICM in place.
- The results (when projected annually using the cluster analysis) will reveal the anticipated impact ICM has on total peak-period delay.

3.6 Data Needs and Availability

Table B-3 summarizes data collection requirements to calculate incident impacts on delay, as well as the availability of data throughout the various stages of the ICM initiative.

Table B-5. Data Needs and Availability for Incident Impacts on Delay

Data Collection Needed	Pre-ICM	Post-ICM	From Model
Freeway Delay	Yes	Yes	Yes
Arterial Delay	N/A	N/A	N/A
Transit Delay	Partial (Metro Transit only)	Yes	Yes
HOT Lane Delay	Yes	Yes	Yes

4. Performance Measure 3 – Maximum Travel Time Reliability

Incidents or special events can cause commuters to experience deviations from their expected travel times. As a result, travelers often factor some 'buffer' time into their trip planning. Reliable travel times, even during incidents and special events, would allow travelers to reduce the 'buffer' time they allocate in the event that incidents cause them delay.

Maximum travel time reliability will be a measure used to determine the impact ICM has on Goal 1 (Mobility and Reliability).

4.1 Anticipated Impacts of ICM on Travel Time Reliability

Travel times typically increase as travelers encounter slow or stopped conditions. In the post-ICM case, even when slow conditions exist, travelers would be informed of optional routes or modes to maintain travel times as close as possible to those during normal conditions. Additional ICM strategies will help to maintain travel speeds on alternate routes and, therefore, further support consistent travel times.

4.2 Hypothesis of ICM Impact on Travel Time Reliability

The hypothesis is that for the post-ICM case, the maximum travel times experienced during incidents and special events will be reduced.

4.3 Measures of Effectiveness of ICM Impacts on Travel Time Reliability

Travel Time MOE #5 – Percent reduction in the maximum travel time on the route impacted by the incident.

4.4 Defining a Measurable Value for Travel Times in the I-394 Corridor

For purposes of the ICM AMS phase, travel time measurements will be as follows:

- The maximum travel time for individual routes is defined as the time taken for travelers to traverse the portion of the route on the I-394 Corridor.
- In order to support modeling of impacts of incidents on maximum travel times along routes impacted by the incident in the AM peak period, travel times will be measured/computed for the following:
  - EB I-394 general purpose lanes (from I-494 to I-94);
  - EB I-394 HOT lanes (from I-494 to I-94); and
  - Transit travel times from park-and-ride facilities near I-494 to downtown using I-394.
- Travel times will be collected/modeled for 15-minute periods from 6:00 a.m. to 9:00 a.m. during nonincident (typical) days in order to determine typical travel times along all routes. The maximum travel time experienced during the peak period is the value to be used to assess this performance measure.
- Travel times will be collected/modeled for 15-minute periods from 6:00 a.m. to 9:00 a.m. during incident days to determine comparable travel times. The maximum travel time recorded along any approach will be gathered and used in this comparison.

4.5 Analyzing the Impacts of ICM on Travel Time Reliability

- Travel times will be measured for the designated routes, and the maximum travel time will be determined for each peak period (6:00 a.m. to 9:00 a.m.).
- The maximum travel time for each route/mode will be used to assess the maximum travel time and compute the reliability.
- The simulation model will be run to model the impacts of each of these four categories of incidents (using the actual circumstances of sample incidents to direct the model) for the pre-ICM case. The model will be used to produce individual maximum travel times for each of the routes.
- Mn/DOT's cluster analysis has identified the percentage of days in a year that encounter each of the four categories of the incidents. Therefore, the range of travel times can be projected to an annual amount.
- The simulation model will be run again for each of the four incident categories for the post-ICM case. The model results will be used to assess the travel time range with ICM in place.

- The results (when projected annually using the cluster analysis) will reveal the anticipated impact ICM has on travel time reliability.

4.6 Data Needs and Availability

Table B-4 summarizes data collection requirements to calculate maximum travel time reliability, as well as the availability of data throughout the various stages of the ICM initiative.

Table B-6. Needs and Availability for Maximum Travel Time Reliability

Data Collection Needed	Pre-ICM	Post-ICM	From Model
Freeway Travel Times	Available - Every 2 minutes	Available - Every 2 minutes	Yes
Transit Travel Times	Partial (Metro Transit only)	Available: - Vehicle-based - Calculated	Yes
HOT Lane Travel Times	Available - Every 2 minutes	Available - Every 2 minutes	Yes

5. Performance Measure 4: Influence on Travelers Behavior

5.1 Anticipated Impacts on Travelers Behavior

The ICM strategies include improved information to travelers that will influence decision-making and cause travelers to change travel behavior.

5.2 Hypothesis of ICM Impact on Travelers Behavior

Through ICM deployment and operation, travelers will voluntarily make mode, route, departure time, or destination decisions based on improved knowledge of the corridor conditions.

5.3 Measures of Effectiveness

Travelers Behavior MOE #6 – Percent shift to transit during incidents.

Travelers Behavior MOE #7 – Increased park-and-ride use during incidents.

Travelers Behavior MOE #8 – Percent shift in routes during times when ICM messages are disseminated to travelers.

Travelers Behavior MOE #9 – Percent change in departure time adjustments.

5.4 Data Needs and Availability

Table B-5 summarizes data collection requirements to calculate influence on travelers' behavior, as well as the availability of data throughout the various stages of the ICM initiative.

Table B-7. Data Needs and Availability for Influence on Travelers' Behavior

MOE	Data Needed	Pre-ICM	Post-ICM	Modeling
Transit Shift during Incidents	Transit – Ridership (nonincident and incident days)	Available	Available	Available
Increased Park-and-Ride Use during Incidents	Transit – Park-and-Ride Occupancy	Not Available	Available	Available
Route Shifts	Fwy – Mainline Volumes Fwy – Ramp Volumes Records of Information Dissemination – DMS messages – Push information – Web dissemination	Available Available Available Not Available Limited	Available Available Available Available Available	Available Available Available Available Available
Changes in Departure Times	User Feedback on Surveys	Limited		

6. Matrix of MOEs, Hypotheses, and Data Needs

Table B-6 lists MOEs, hypotheses, and data needs for four performance measure areas.

Table B-8. Matrix of MOEs, Hypotheses, and Data Needs

Performance Measure Area	Hypothesis	Measures of Effectiveness	Data Needs	Pre-ICM	Post-ICM	Modeling
Throughput	ICM will maintain consistent corridor-wide throughput, and avoid throughput reductions during incidents or special events.	*MOE #1* – Percent change in the loss of traveler throughput during incidents or special events. *MOE #2* – Percent change in the time to recovery of throughput reduction caused by incidents or special events.	• Fwy (GP lanes) – Volume data • Fwy (Tolled vehicle) – Volume • Fwy (HOV) – Volume • Arterial – Volume data • Transit – Ridership per route	• Available • Available • Available • 15-minute volume • Metro Transit only	• Available • Available • Available • 15-minute volume • Metro Transit only	• Available • Available • Available • Available • Metro Transit only
Delay	ICM will reduce the frequency and extent to which travelers experience an increase beyond the normal levels of delay.	*MOE #3* – Percent change in the annual increase in traveler hours of delay experienced by freeway and transit travelers during incidents and special events. *MOE #4* – Percent change in the number of peak periods where freeway and transit travelers experience an increased delay of more than 10 percent.	• Fwy (GP lanes) – Speed/TT • Fwy (Tolled vehicle) – Speed/TT • Fwy (HOV) – Speed/TT • Transit – Vehicle travel time – Vehicle headway	• Available • Available • Available • Available	• Available • Available • Available • Available	• Available • Available • Available • Available

Performance Measure Area	Hypothesis	Measures of Effectiveness	Data Needs	Pre-ICM	Post-ICM	Modeling
Travel Time Reliability	Post-ICM, the maximum travel times experienced during incidents and special events will be reduced.	*MOE #5* – Percent reduction in the maximum travel time on the route impacted by the incident.	• Fwy (GP lanes) – Speed/TT • Fwy (Tolled vehicle) – Speed/TT • Fwy (HOV) – Speed/TT	• Available • Available • Available	• Available • Available • Available	• Available • Available • Available
Influence on Travelers Behavior	Through ICM deployment and operation, travelers will voluntarily make mode, route, departure time, or destination decisions based on improved knowledge of the corridor conditions.	*MOE #6* – Percent shift to transit during incidents.	• Transit – Ridership (nonincident and incident days).	• Available	• Available	• Available
		MOE #7 – Increased park-and-ride use during incidents.	• Transit – Park-and-ride occupancy	• Not Available	• Available	• Available
		MOE #8 – Percent shift in routes during times when ICM messages are disseminated to travelers.	• Fwy – Mainline Volumes – Ramp Volumes. • Records of Information dissemination – DMS messages, – Push information, and – Web dissemination.	• Available • Available • Available • Not Available • Limited	• Available • Available • Available • Available • Available	• Available • Available • Available • Available • Available
		MOE #9 – Percent change in departure time adjustments.	• User Feedback on Surveys.			

APPENDIX C. U.S. DOT Guidance on Performance Measures

Appendix C presents the U.S. DOT guidance for Mobility and Reliability Performance Measures utilizing outputs from simulation models.

Calculation Procedures for Key Integrated Corridor Performance Measures from Simulation Outputs

A core element of the ICM initiative is the identification and refinement of a set of key performance measures. These measures represent both the bottom line for ICM strategy evaluation, and define what "good" looks like among key corridor stakeholders. To date, the emphasis on performance-driven corridor management among the participating Pioneer Sites has been on measures derived from observed data. In the AMS phase of the effort, however, attention has turned to producing comparable measures derived from simulation outputs. This document provides a detailed process by which a set of key national measures of corridor performance can be calculated. It is the intent of the ICM program, and this document, that these processes will be implemented consistently in the three participating AMS sites applying the ICM AMS methodology.

This document provides a detailed description of how measures of ***delay***, ***travel time reliability,*** and ***throughput*** are calculated from simulation outputs. A brief discussion of travel time variance also is provided, given that travel time variance measures are used in ICM-related, benefit/cost calculations. The algorithmic approaches defined here are software independent; that is, this process can be implemented with outputs from any of the time-variant simulation tools utilized in the three participating ICM AMS sites. The document begins with a discussion of the calculation of travel time, which informs both a calculation of delay, as well as travel time reliability. Next, we provide a discussion of how corridor throughput is defined and measured. The document concludes with a discussion of how these measures are used to make comparisons between system performance in the pre-ICM case, and in one or more distinct post-ICM cases.

Travel Time

Our basic unit of observation in calculating ICM-related performance measures is a trip i made between an origin o, finishing at a destination d, starting at a particular time τ' using mode m. We record travel time from a single run of the simulation under operational conditions k for this unit of observation as $t_i^k = t_{o,d,\tau',m}^k$.[7] *Operational conditions* here refer to a specific set of simulation settings reflecting a specific travel demand pattern and collection of incidents derived from a cluster analysis of

[7] In the case where multiple random seeds are varied, but the operational conditions are identical, this travel time represents an average for a single trip in across the multiple runs. Also, note that this discussion of measures assumes that we are calculating measures for a single case (e.g., pre-ICM); later we will address comparisons between cases.

observed traffic count data and incident data. An example of an operational condition would be an a.m. peak analysis with five percent higher than normal demand and a major arterial incident.

First, for this particular run(s) representing a specific operational condition, we calculate an average travel time for trips between the same OD pair that begin in a particular time window. Let τ represent this interval (e.g., an interval between 6:30 a.m. and 6:45 a.m.) and $\mathbf{I}^k_{o,d,\tau,m}$ the set of $n^k_{o,d,\tau,m}$ trips from o to d starting in interval τ under operational condition k using mode m. Note that $\mathbf{I}^k_{o,d,\tau,m}$ is a collection of trips and $n^k_{o,d,\tau,m}$ the scalar value indicating the number of trips contained in $\mathbf{I}^k_{o,d,\tau,m}$.

The classification of travel mode may be determined independently at each site, but the breakdown should capture the combination of all modes utilized in making the trip. For example, one may choose to classify non-HOV auto trips as a mode separately from non-HOV auto/HOV/walk trips to track the performance of travelers utilizing park-and-ride facilities. However, any classification of modes must be mutually exclusive and collectively exhaustive; that is, $\bigcup_m \boldsymbol{I}^k_{o,d,\tau,m} = \boldsymbol{I}^k_{o,d,\tau}$ and $\sum_m n^k_{o,d,\tau,m} = n^k_{o,d,\tau}$.

The average travel time of trips with origin and destination by mode starting in this time interval is:

$$T^k_{o,d,\tau,m} = \frac{\sum_{i \in \mathbf{I}^k_{o,d,\tau}} t^k_i}{n^k_{o,d,\tau,m}}$$

(Equation 1)

The calculation of Equation 1 also must include some estimated travel time for trips that cannot reach their destinations by the end of the simulation period. Later in this document, we will discuss the method for estimating travel times for these trips still underway when the simulation ends.

Next, we calculate the average travel time for this same set of trips across all operational conditions. Let k be a specific operational condition and the set of all conditions K. Note that each condition has a probability of occurrence p_k and $\sum_k p_k = 1$. Equation 2 finds the average travel time by mode for all trips from o to d starting in interval τ over all conditions $k \in K$:

$$T_{o,d,\tau,m} = \sum_{k \in K} T^k_{o,d,\tau,m} p_k$$

(Equation 2)

The average number of trips by mode from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau,m} = \sum_{k \in K} n^k_{o,d,\tau,m} p_k$$

(Equation 2a)

Combining across modes, the average travel time of trips from o to d starting in interval τ under operational condition k:

$$T^k_{o,d,\tau} = \frac{\sum_m T^k_{o,d,\tau,m} n^k_{o,d,\tau,m}}{n^k_{o,d,\tau}}$$

(Equation 3)

The average travel time for all trips from o to d starting in interval τ over all conditions $k \in K$:

$$T_{o,d,\tau} = \sum_{k \in K} T^{k}_{o,d,\tau} p_k$$

(Equation 4)

The average number of trips from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau} = \sum_{k \in K} n^{k}_{o,d,\tau} p_k$$

(Equation 4a)

Equation 5 defines the trip-weighted average travel time of the system across all o, d, τ :

$$T = \frac{\sum_{\forall o,d,\tau} T_{o,d,\tau} \, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}}$$

(Equation 5)

Delay

Delay can be broadly defined as travel time in excess of some *subjective minimum* travel time threshold. Often, discussions of delay focus solely on roadway-only travel focus on either travel time at posted speeds or 85th percentile speeds. Delay for ICM must be defined differently since ICM explicitly includes multimodal corridor performance. Instead, we directly identify delay at the o, d, τ level by deriving a zero-delay threshold by mode $T^{0}_{o,d,\tau,m}$.

This can be derived from travel time outputs over all operational conditions:

$$T^{0}_{o,d,\tau,m} = \min_{k \in K} \left\{ T^{k}_{o,d,\tau,m} \right.$$

(Equation 6)

In some cases, the cluster analysis will group low-demand, nonincident conditions into a large, high-probability operational condition. In this case, it is possible that a notionally "low" demand pattern will still produce significant congestion in the corridor, particularly in a peak-period analysis.

For this reason, the minimum threshold also may be calculated as the travel time derived in the pre-ICM case under a substantially reduced demand pattern with no incidents or weather impacts. The reduced demand pattern should generate a large enough number of trips to generate travel time statistics by mode for every set of trips from o to d starting in interval τ (i.e., $n^{0}_{o,d,\tau,m} > 0 \;\; \forall \; o, d, \tau, m$). At the same time, the reduced demand should generate no volume-related congestion in the network.

Alternatively, $T^{0}_{o,d,\tau,m}$ may be estimated directly from model inputs. For consistency, however, the travel time associated with these thresholds should include expected transfer time between modes and unsaturated signal delay as in the case where a low-demand pattern is used to drive a zero-delay model run.

Once zero-delay thresholds $T^0_{o,d,\tau,m}$ are identified, average trip delay can be calculated by mode for each o,d,τ,m:

$$D_{o,d,\tau,m} = \max\left[T_{o,d,\tau,m} - T^0_{o,d,\tau,m}, 0\right]$$ (Equation 7)

Combining across modes, the average delay for trips from o to d starting in interval τ:

$$D_{o,d,\tau} = \frac{\sum_m D_{o,d,\tau,m}}{n_{o,d,\tau}}$$ (Equation 8)

Systemwide average trip delay (Equation 9):

$$D = \frac{\sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}}$$ (Equation 9)

Aggregating this average delay over all trips produces total system delay (Equation 10):

$$\widehat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}$$ (Equation 10)

Travel Time Reliability

Corridor reliability measures are inherently measures of outlier travel times experienced by a traveler making the same (or similar) trip over many days and operational conditions. This is convenient, given that we already have defined and organized travel time measures from the simulation with respect to trips from o to d starting in interval τ over all conditions $k \in K$. Just as in the case of the subjective notion of delay as travel time in excess of some minimum threshold, the notion of what reliable travel depends on a *relative maximum* acceptable travel time threshold. For the ICM AMS effort, as in many studies with a travel reliability measure, a threshold based on the 95th percentile travel time is selected. Note that this percentile is calculated considering travel times for similar trips (i.e., o,d,τ) with respect to travel time variation induced by changes in operational conditions $k \in K$.

To identify the 95th percentile travel time, first we generate an ordered list of travel times by o,d,τ:

$$\mathbf{T}_{o,d,\tau} = \left[T^1_{o,d,\tau}, T^2_{o,d,\tau}, \cdots, T^J_{o,d,\tau}\right], \text{ where } T^j_{o,d,\tau} \le T^{j+1}_{o,d,\tau} \text{ for all } j = 1 \cdots J$$ (Equation 11)

The 95th percentile travel time from this list is identified using the probabilities associated with each operational condition.

$$T^{[95]}_{o,d,\tau} = T^{j}_{o,d,\tau} \text{ where } \sum_{k=1}^{j} p_k = 0.95$$ (Equation 11a)

Note the array of travel times $\mathbf{T}_{o,d,\tau}$ represents levels on a linear step-function. This implies that, if 17.4 minutes is the travel time associated with an operational condition occupying the 92nd through 98th travel time percentile, we simply use the 17.4-minute travel time as the 95th percentile value. Also note that the specific operational conditions under which the 95th percentile travel time is found will vary among o, d, τ. For example, a major freeway incident creates congestion and high travel times for trips that originate upstream of the incident location, but creates free-flowing and uncongested conditions for trips that originate downstream of the incident location.

Equation 12 defines planning time index, the ratio of the 95th percentile travel time to the zero-delay travel time for trips from o to d starting in interval τ over all conditions $k \in K$:

$$\rho_{o,d,\tau} = \frac{T^{[95]}_{o,d,\tau}}{T^{0}_{o,d,\tau}}$$ (Equation 12)

Average systemwide planning time index considers all o, d, τ weighted average by trip volume:

$$\rho = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}}$$ (Equation 13)

Variance in Travel Time

Variance in travel time can be calculated in a variety of ways. The key here is that some care must be taken to isolate the specific variation of interest.

For example, variance in travel time among members of the same time interval in a single run is the variance of $t_{o,d,\tau'}$ with respect to $\tau' \in \tau$:

$$V^{k}_{o,d,\tau} = \frac{\sum_{\tau' \in \tau} \left(t^{k}_{o,d,\tau'} - T^{k}_{o,d,\tau}\right)^2}{n^{k}_{o,d,\tau} - 1}$$ (Equation 14)

If we seek to identify the variance in conditions that are reflective of a traveler making the same trip at roughly the same time on a regular basis, however, our unit of observation is the o, d, τ trip-making window with respect to $k \in K$. In this case, the calculation of variance also includes the consideration of the probabilities of each operational condition.[8]

$$V_{o,d,\tau} = \sum_{k \in K} \left(T^k_{o,d,\tau} - T_{o,d,\tau}\right)^2 p_k$$

(Equation 14a)

The average variance among all o, d, τ is a weighted average of the variances:

$$V = \frac{\sum_{\forall o,d,\tau} V_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}}$$

(Equation 14b)

Throughput

The role of a throughput measure in ICM is to capture the primary product of the transportation system: travel. Particularly in peak periods, the capability of the transportation infrastructure to operate at a high level of efficiency is reduced. One of the goals of ICM is to manage the various networks (freeway, arterial, transit) cooperatively to deliver a higher level of realized system capacity in peak periods. While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In the ICM AMS effort, we use the term *corridor throughput* to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. We do not consider freight throughput in these calculations, although this could be revisited at a later date.

In order to support throughput measures, additional trip data need to be generated as simulation outputs. For each trip i made between an origin o , finishing at a destination d , starting at a particular time τ' we obtain from the simulation the travel time $t^k_{o,d,\tau'}$ and a distance traveled $s^k_{o,d,\tau'}$. In some cases, trip-level outputs from the simulation are only available at a vehicle level, so some trips may have multiple passengers associated with that trip (e.g., in the case of carpool travel). Let $x^k_{o,d,\tau'}$ represent the number of travelers associated with a particular trip record.

Passenger-miles traveled (PMT) are accumulated using a process similar to travel time. First, we convert individual trip PMT into an average PMT for trips from origin o to destination d with a trip start in time interval τ .

[8] We make a simplifying assumption that the unbiased variance is well approximated by the biased variance in this case; that is, we do not estimate the sum of the individual weights squared.

$$X_{o,d,\tau}^{k} = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^{k}} s_i^k x_i^k}{n_{o,d,\tau}^{k}}$$

(Equation 15)

For trips that cannot be completed before the end of the simulation, see the following section for the estimation of total trip distance.

Equation 16 finds the average PMT for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$X_{o,d,\tau} = \sum_{k \in K} X_{o,d,\tau}^{k} p_k$$

(Equation 16)

Equation 17 defines the aggregate PMT across all o, d, τ:

$$X = \sum_{\forall o,d,\tau} X_{o,d,\tau} n_{o,d,\tau}$$

(Equation 17)

Passenger-miles delivered (PMD) and passenger-trips delivered (PTD) are measures that introduce notions of travel quality into throughput. Simple PMT measures often cannot differentiate between a well-managed system and a poorly managed system because passenger-trip distances are counted equally, regardless of trip duration. In other words, a five-mile trip completed in 15 minutes counts equally with the same five-mile trip completed in two hours. Here, we restrict the accounting of passenger-miles traveled (or passenger-trips delivered) to trips that successfully complete their trips prior to the end of the simulation (or some other logical time-point). Let $\dot{\mathbf{I}}_{o,d,\tau}^{k}$ be the set of from o to d starting in interval τ under operational condition k that complete their trip before the simulation ends (or some other logical time-cutoff).

Equation 18 shows passenger-trips delivered (PTD) calculated at the o, d, τ level.

$$Y_{o,d,\tau}^{k} = \frac{\sum_{i \in \dot{\mathbf{I}}_{o,d,\tau}^{k}} x_i^k}{n_{o,d,\tau}^{k}}$$

(Equation 18)

Equation 19 finds the average PTD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Y_{o,d,\tau} = \sum_{k \in K} Y_{o,d,\tau}^{k} p_k$$

(Equation 19)

Equation 20 defines the aggregate PTD across all o, d, τ:

$$Y = \sum_{\forall o,d,\tau} Y_{o,d,\tau}\, n_{o,d,\tau}$$

(Equation 20)

Passenger-miles delivered (PMD) is a distance-weighted measure of throughput based on PTD:

$$Z^k_{o,d,\tau} = \frac{\sum_{i \in \mathbf{I}^k_{o,d,\tau}} s^k_i x^k_i}{n^k_{o,d,\tau}}$$

(Equation 21)

Equation 22 finds the average PMD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Z_{o,d,\tau} = \sum_{k \in K} Z^k_{o,d,\tau}\, p_k$$

(Equation 22)

Equation 23 defines the aggregate PMD across all o,d,τ:

$$Z = \sum_{\forall o,d,\tau} Z_{o,d,\tau}\, n_{o,d,\tau}$$

(Equation 23)

For example, in the Dallas ICM Corridor, the simulation period is from 5:30 a.m. to 11:00 a.m., while the peak hours are from 6:30 a.m. to 9:00 a.m. It is anticipated that with or without an ICM strategy in place, all trips that begin in the peak period should be completed before the simulation ends at 11:00 a.m. In this case, there may be little difference in PMT or PMD when 11:00 a.m. is used as the logical time cutoff. In order to measure the peak capability of the system to deliver trips, the set of trips counting towards PMD could potentially be restricted to those trips that can both begin and complete their trips in the peak period (6:30 a.m. to 9:00 a.m.). At this point, it is premature to define a specific time cutoff for PMD to be applied in all three sites.

Restricting the calculation of measures to selected cohorts also is relevant to the calculation of delay and travel time reliability measures. Although peak periods vary among the AMS sites in terms of the onset and duration of congestion, a consistent set of trips that contribute to measuring calculation (others simply run interference) should be identified. As in the case of the throughput time cutoff point, U.S. DOT may wish to prescribe specific times in the future.

At this time, it is unclear whether PMT, PMD, or PTD will be the selected performance measure for corridor throughput, pending clarification that all ICM models can support these measures.

Estimation of Travel Times and Travel Distance for Incomplete Trips

Trips that cannot complete their trips by the time that the simulation ends are still included in the calculation of all delay and travel time calculations. Our approach is to estimate total travel time, including any additional time that would be required to complete the trip given the average speed of travel.

First, let $\ddot{\mathbf{I}}^{0}_{o,d,\tau}$ be the set of $n^{0}_{o,d,\tau}$ trips from o to d starting a trip in time interval τ that can be completed under the low-demand operational condition used to identify the zero-delay travel times.

The average distance traveled over these trips is:

$$\ddot{X}^{0}_{o,d,\tau} = \frac{\sum_{i\in\ddot{\mathbf{I}}^{0}_{o,d,\tau}} s_i^k}{n^{0}_{o,d,\tau}}$$

(Equation 24)

Next, let $\overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$ be the set trips from origin o, destination d starting a trip in time interval τ that *cannot* be completed under operational condition k. For all $i \in \overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$, let $\overleftarrow{x}_i^k$ be the distance traveled on the trip i up to the point where the simulation ends, and let $\overleftarrow{t}_i^k$ be the travel time on trip i up to the point where the simulation ends.

Average travel speed for a trip that cannot be completed is expressed in Equation 25:

$$\overleftarrow{v}_i^k = \frac{\overleftarrow{x}_i^k}{\overleftarrow{t}_i^k}$$

(Equation 25)

Estimated total trip travel time for a trip that cannot be completed before the simulation ends is the accumulated travel time, plus the time to travel the remaining distance at average trip speed:

$$t_i^k = \overleftarrow{t}_i^k + \max\left\{\left(\ddot{X}^{0}_{o,d,\tau} - \overleftarrow{x}_i^k\right)\overleftarrow{v}_i^k, 0\right\}$$

(Equation 26)

$$x_i^k = \max\left\{\ddot{X}^{0}_{o,d,\tau}, \overleftarrow{x}_i^k\right\}$$

(Equation 27)

Comparing Pre- and Post-ICM Cases

All of the travel time and throughput measure calculation procedures defined above are conducted under a single set of simulation settings reflecting a specific set of corridor management policies, technologies, and strategies (here referred to as a case, but often called an alternative). The complete suite of delay, travel time reliability, and throughput measures is calculated independently for each case (e.g., pre-ICM). Comparisons of the resulting measures then are made to characterize corridor performance under each case.

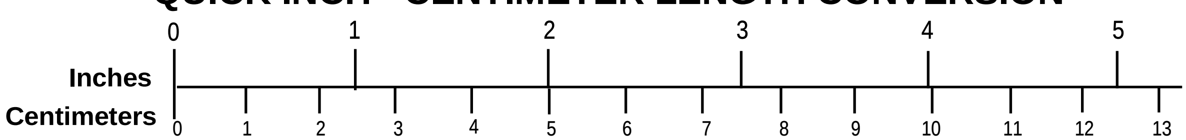
Comparing Observed and Simulated Performance Measures

These few key measures have been defined in detail for national consistency across all AMS sites. Sites also have identified measures. This document has dealt in detail with the calculation of measures from simulation outputs. However, the calculation of comparable measures using observed data demands an equivalent level of detailed attention. These observed measures will be critical in the AMS effort to validate modeling accuracy and in performance measurement in the demonstration phase. Because of the nature of the simulation output, the modeling analyst is able to resolve and track performance at a level of detail that is not available to an analyst working with field counts, speeds, and transit passenger-counter outputs. However, it is the responsibility of the site and the AMS contractor to ensure that these measures are similar in intent, if not in precise calculation. In many cases, the simulation tools or their basic outputs can be manipulated to produce measures quite comparable with field data. An example of this is in throughput calculation, where a site may wish to pursue a screenline passenger throughput measure from field data. In addition to the system-level throughput measures detailed above, the simulation model can be configured to produce passenger-weighted counts across the same screenline to match the field throughput measure.

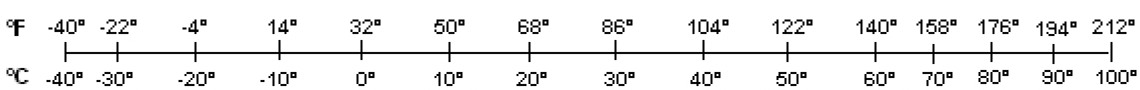
APPENDIX D. Metric/English Conversion Factors

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH (APPROXIMATE)**	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA (APPROXIMATE)**	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT (APPROXIMATE)**	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME (APPROXIMATE)**	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE (EXACT)**	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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