# U.S. 75 Dallas, Texas, Analysis Plan

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**16. Abstract**

This AMS Analysis Plan for the U.S. 75 Pioneer Corridor outlines the various tasks associated with the application of the ICM AMS tools and strategies 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 Dallas, Texas, 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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# 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 U.S. 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 postdemonstration 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:

- Helping 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.
- Helping estimate the benefit resulting from ICM across different transportation modes, ITS systems, 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.

- Transferring 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 U.S. 75 Pioneer Corridor*** outlines the various tasks associated with the application of the ICM AMS tools and strategies to the corridor, in support of a benefit-cost assessment of the proposed strategies. The organization of this Analysis Plan is as follows:

- **Section 2** provides a brief description of the Pioneer Corridor in Dallas, Texas, 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 a schedule and a resource guide 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-payoff and high-payoff ICM strategies, and help prioritize ICM investments based on expected performance.

# Chapter 2. U.S. 75 Corridor Site and AMS Methodology

The U.S. 75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The U.S. 75 Corridor has been defined at two levels. The immediate corridor consists of the freeway, a light-rail line, and arterial streets within approximately two miles of the freeway. In addition, a full "travel shed" influence area has been defined that includes additional alternate modes and routes that may be affected by a major incident or event. The travel shed area is generally bound by downtown Dallas to the south, the Dallas North Tollway to the west, SH 121 to the north, and a combination of arterials streets and the Dallas Area Rapid Transit (DART) Blue Line to the east. The following sections provide a detailed overview of the study corridor.[1]

## 2.1 U.S. 75 Corridor Description

U.S. 75 is Dallas' first major freeway, completed around 1950, and fully reconstructed with cantilevered frontage roads over the depressed freeway section and reopened in 1999 with a minimum of eight general-purpose lanes. The freeway mainlines carry more than 250,000 vehicles a day, with another 20,000 to 30,000 on the frontage roads.

The U.S. 75 Corridor study area includes the freeway, continuous frontage roads, light-rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and intelligent transportation systems. A concurrent-flow, high-occupancy vehicle (HOV) lane in the corridor opened in December 2007.

The corridor study area also contains the first light-rail line, the Red Line, constructed in Dallas as part of the 20-mile DART starter system and opened in 1996. The Red Line now expands into the cities of Richardson and Plano, and passes next to the cities of Highland Park and University Park. This facility operates partially at-grade and partially grade-separated through deep-bored tunnels under U.S. 75. In addition, the Blue Line operates near downtown Dallas and extends along the eastern edge of the corridor boundary. Finally, in downtown Dallas, the light-rail lines connect to the regional commuter-rail line, the Trinity Express.

The U.S. 75 Corridor study area serves: 1) commuting trips into downtown Dallas via the freeway, bus routes, light-rail line, and arterial streets; 2) a significant number of reverse commuters traveling to commercial and retail developments in the northern cities and neighborhoods; 3) regional traffic during off-peak-periods; and 4) interstate traffic into Oklahoma, since the freeway is a continuation of Interstate 45. Finally, the corridor also is a major evacuation route and experienced significant volumes during the Hurricane Rita evacuation in 2005.

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[1] Concept of Operations for the U.S. 75 Integrated Corridor, Dallas, Texas, March 2008.

There are three major freeway interchanges in the corridor study area. In the southern section, U.S. 75 has an interchange with the downtown freeway network connecting to Interstate 45 and Interstate 35E. At midpoint there is a newly constructed interchange with Interstate 635, while in the northern section there is an interchange with the President George Bush Turnpike (PGBT). Figure 2-1 illustrates the U.S. 75 Corridor with the primary corridor study area highlighted and the roadways included in the study area.

## 2.2 Modeling Approach

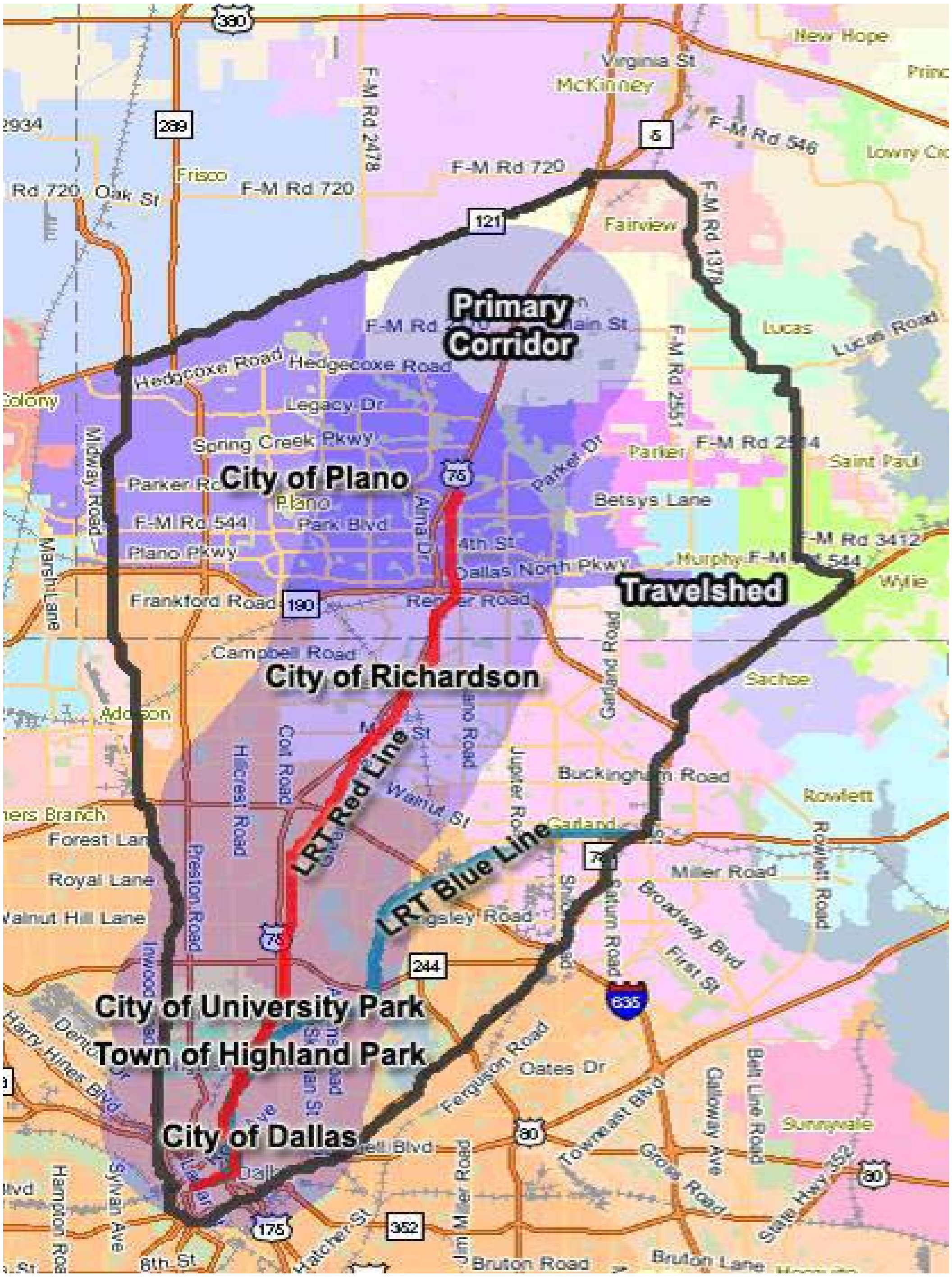
The modeling approach that emerged from the analysis of capabilities found in existing AMS tools, as well as from the ICM Test Corridor project, is an ***integrated platform that can support corridor management planning, design, and operations by combining the capabilities of existing tools***. The integrated 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 applied 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.

In order to estimate the full benefits of the ICM strategies for the U.S. 75 Corridor, the simulation period for the mesoscopic model will need to encompass not only the time that it took to reopen the lane(s) after an incident (incident clearance time), but the time that it took to return to normal operations. Based on a cluster analysis (see Section 3), the time of day with the highest probability for an incident to occur and the average time it took to return to normal operating conditions were assessed. As such, the Dallas AMS team decided to use a simulation period covering the hours of 5:30 a.m. to 11:00 a.m. It also was determined that the a.m. peak would allow the testing of a greater number of strategies than the p.m. peak, including strategies that support mode shift.

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

**Figure 2-1. Location and Geographic Boundaries of Corridor**




[Source: NCTCOG website dfwmaps.com.]

## Travel Demand Forecasting Model

Travel demand models estimate demand based on projections of household and employment characteristics and predict preferences in activity location, time-of-day, mode, and route choice. The North Central Texas Council of Governments (NCTCOG), Dallas' metropolitan planning organization (MPO), maintains the regional travel demand model in TransCAD, with 1999 being the most recent validation year. NCTCOG's model currently is being revalidated for 2004, but it will not be available for use in this study. The static nature of NCTCOG's travel demand model is not entirely compatible with the dynamic nature of travel choices during an incident situation. DIRECT, the selected mesoscopic model for the U.S. 75 Corridor study area, models the diversion to different routes or 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 traveler decisions and their impact to network conditions.

Therefore, the NCTCOG model will be used as the primary source for the vehicular trip tables and networks utilized by DIRECT. NCTCOG has trip tables and networks available for 2007, and it was agreed that the base year for the U.S. 75 Corridor study area will be 2007. In addition, available coefficients (e.g., value of time, operating cost per mile, etc.) and variables from the travel demand model will be reviewed, and their transferability to the generalized cost equation incorporated in DIRECT will be assessed. While travel demand subarea procedures allow for the extraction of the vehicular demand for the U.S. 75 Corridor study area, similar procedures are not available for the transit component. Therefore, the Dallas AMS team will utilize the DART on-board survey to develop an estimate of the transit origin-destination (OD) trip table. The various levels of interaction, migration of information between NCTCOG's model and DIRECT, and use of DART's survey will be further documented in a separate report describing the calibration and validation of the DIRECT model.

## Mesoscopic Simulation Model

Mesoscopic models combine properties of both microscopic and macroscopic simulation models. Similar to microscopic models, the mesoscopic model's unit of traffic flow is the individual vehicle. 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 models, but are superior to travel demand models in that they can evaluate dynamic traveler diversions in large-scale networks.

For the analysis of this corridor, the most recent version of DIRECT, developed by the Southern Methodist University (SMU), will be used. The model will support the analysis of the dynamic impact of ICM strategies, such as HOT lanes, route shifts, mode shifts, and corridor-specific traveler information (pretrip and en-route).

In DIRECT, the traveler's mode and route are generated so that each traveler is assigned to a route-mode option that: 1) minimizes the traveler's generalized cost; and 2) matches the traveler's mode preference options which are influenced by the willingness to car pool and to use transit. As part of the model input, each origin-destination pair is assigned a value to represent the percentage of travelers who are willing to use transit (i.e., considering transit in their mode choice set either as pure mode or combined with private car) or carpool. An estimate of the willingness to use transit is obtained as the ratio between the number of transit travelers recorded in the DART on-board transit survey and the total number of travelers estimated for each origin-destination pair. Each origin-destination pair also is assigned a value to represent the percentage of travelers who are willing to carpool. The regional demand model provides information on the number of carpooling travelers who use the HOV facility, and number of carpooling travelers who do not use any HOV facility. As an estimate of the willingness to carpool, for an origin-destination pair, the sum of HOV and non-HOV users is first multiplied by the average car occupancy, and then divided by the total number of travelers for this pair. An average car occupancy of two persons per vehicle is assumed. Based on the DART survey, the average willingness to use transit was estimated at 44 percent. For origin-destination pairs that the DART survey did not provide estimates for, the willingness to use transit was set at four percent.[2] Based on these estimates and the regional model data, the average transit and carpool willingness were 5.8 and 21.5 percent, respectively.

Based on the willingness to use transit or carpool of a traveler, the following four sets of mode-route options are evaluated at five-minute intervals:

- **Set I –** Routes for SOVs (drive-alone);
- **Set II –** Routes for HOVs (carpool);
- **Set III –** Routes for park-and-ride (excluding carpool); and
- **Set IV –** Routes for transit (pure transit).

For example, if the traveler is not willing to use transit and not willing to carpool, then the traveler will choose a route from Set I. On the other hand, if the traveler is willing to use transit and not willing to carpool, then the traveler will choose from Sets I, III, or IV. Another case could be that the traveler is not willing to use transit but is willing to carpool, then the traveler will choose from Sets I or II.

For each traveler willing to carpool, a search for another traveler is made. This other traveler must satisfy the following conditions:

- Departing from the same origin zone;
- Departing within a given time window (10 minutes);
- Going to the same destination zone; and
- Willing to car pool.

This search is repeated until a maximum of four travelers is reached (i.e., capacity of the private car). If a match is found, this vehicle is marked as HOV, and the route set that includes the HOV facilities is made available as part of the choice set (Sets I and II). If a match is not found, the HOV route options are excluded and the other options are made available (Sets I, III, and IV). Currently, DIRECT does not model a drive-carpool option. As such, all travelers that are eligible to carpool are starting from the same origin node.

The travelers' mode and route choice is done simultaneously and is a function of the congestion evolution in the network. DIRECT utilizes a multiobjective shortest path algorithm coupled with an incremental all-or-nothing rather than a dynamic user equilibrium (DUE) assignment. Travel times along a route are reflective of the link travel times when the traveler is generated (instantaneous travel times), rather than the link travel times at the time the traveler enters the link (experienced travel

[2] The study area is subdivided in 235 zones and the DART survey provided information only for 4.5 percent out of the potential 55,225 OD pairs in the trip table.

times). DIRECT loads each traveler to the shortest vehicular, transit, or park-and-ride path calculated every five minutes according to the generalized cost function shown in Equation 1.

*Generalized Cost = Travel Time x Value of Time + Travel Cost + Transit Cost* (Equation 1)

where:

| | | |
|---|---|---|
| *Travel Time* | = | The sum of in-vehicle time and out-of-vehicle time, where in-vehicle time is estimated from the simulation[3] and out-of-vehicle time (for transit users only) is a function of the transit service headway;[4] |
| *Value of Time* | = | $10 per hour (cars) and $12 per hour (trucks); |
| *Travel Cost* | = | Sum of operating cost and toll (if any), where operating cost is $0.073 per mile, toll is $0.12 to $0.15 per mile; and |
| *Transit Cost* | = | $1 per ride. |

The value of time and the travel and transit costs reflect global values based on NCTCOG's travel demand model documentation (1999 dollars). It is anticipated that some of these values may need to be adjusted during the calibration of the DIRECT model to reflect the nature of travel within the U.S. 75 Corridor study area. Any adjustments will be documented in a separate report describing the calibration and validation of the DIRECT model.

Based on this process, the actual number of travelers that will use transit or carpool depends on the relative value of the generalized cost of the four potential mode-route options: drive alone (single-occupancy vehicle (SOV)), carpool (HOV), park-and-ride, and pure transit (with and without transfers). As such, in a future scenario where the transit and carpool willingness may remain the same, the number of travelers that uses transit or carpool also could change.

At the end of the process, information on each generated traveler is saved in a text file (called the travelers file) describing the trip start time (loading time in the simulation) and the chosen mode and route. These mode-route choices reflect choices established over the long-term under normal (including recurring congestion) traffic conditions and are identified as *"historical routes."*

Figure 2-2 illustrates the modeling framework and the different components of DIRECT. The model can accept as demand input either a file listing the population of travelers; their attributes (including origin, destination, and time of departure) and mode; or a prespecified, time-dependent origin-destination trip table. Each generated traveler is assigned a set of attributes, which includes his/her trip starting time, generation link, final destination, and a distinct identification number. In parallel, transit vehicles are generated according to a predetermined timetable and follow predetermined routes. Prevailing travel times on each link are estimated using the vehicle simulation component, which moves vehicles while capturing the interaction between autos and transit vehicles. DIRECT

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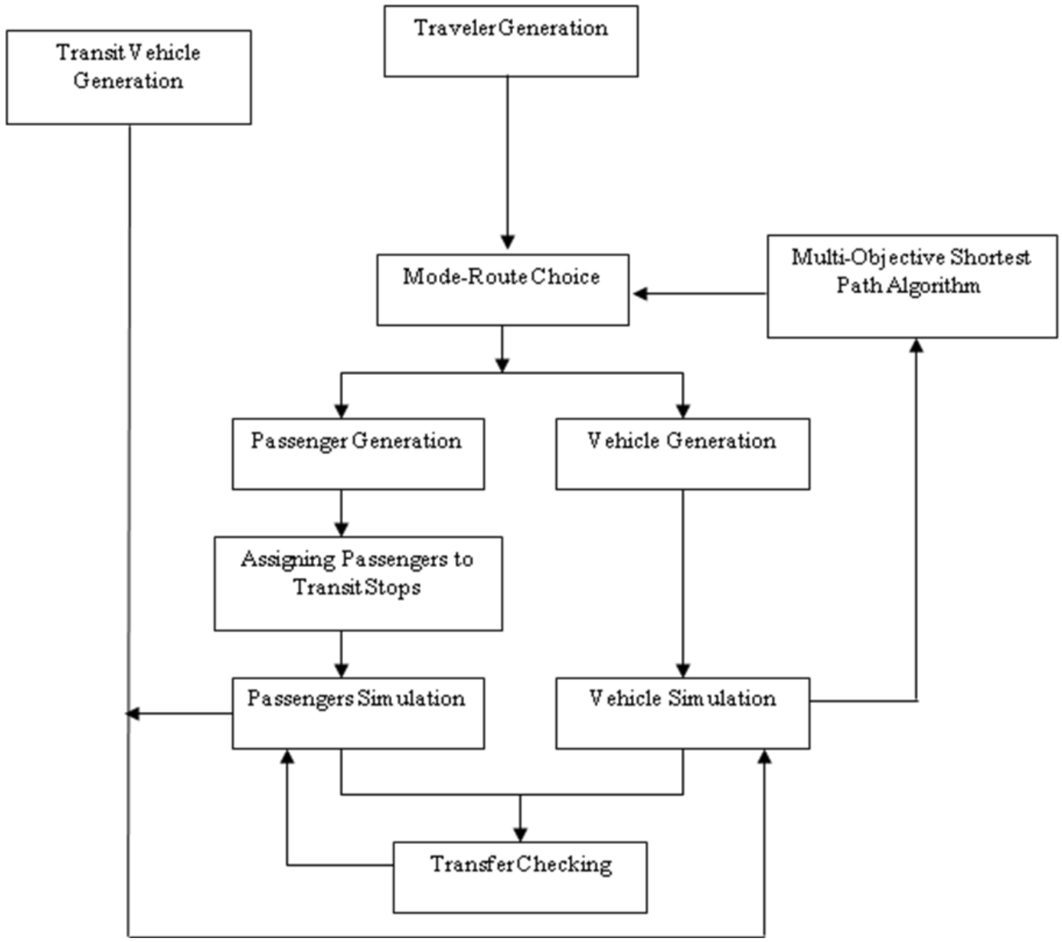
[3] Highway travel times reflect instantaneous travel times. Transit travel times are calculated by network segment and at key decision points in the corridor.

[4] Light rail runs on 10 minutes headway, while buses run on 30 minutes plus headways. Based on general modeling practices, the wait time for light-rail users was assumed to be 50 percent of the headway (i.e.; 5 minutes). For bus users though, a 15-minute wait time (50 percent of 30 minutes) was considered excessive, given that bus users in the Dallas area are aware of the schedules, especially commutes. As such, a wait time of 6 minutes was assumed for all bus users.

also utilizes other measures that may be used by travelers as criteria to evaluate the different mode-route options, including highway tolls, private car operation cost, transit fares, and out of vehicle time.

**Figure 2-2. DIRECT Modeling Framework**




[Source: Southern Methodist University Transportation Research Laboratory, DIRECT Brochure (http://lyle.smu.edu/~khaled/DIRECT_bro.pdf) accessed 9/6/11.]

These measures, along with travel time, are combined in a generalized cost formula utilized in a mode-route decision module activated at fixed intervals to provide travelers with a set of mode-route options. The activation interval (usually in the range of three to five minutes) is set so that the variation in network conditions is captured while retaining desirable computational performance. Travelers evaluate the different mode-route options and choose a preferred one. Based on the available options, a traveler may choose a “pure” mode or a combination of modes to reach his/her final destination.

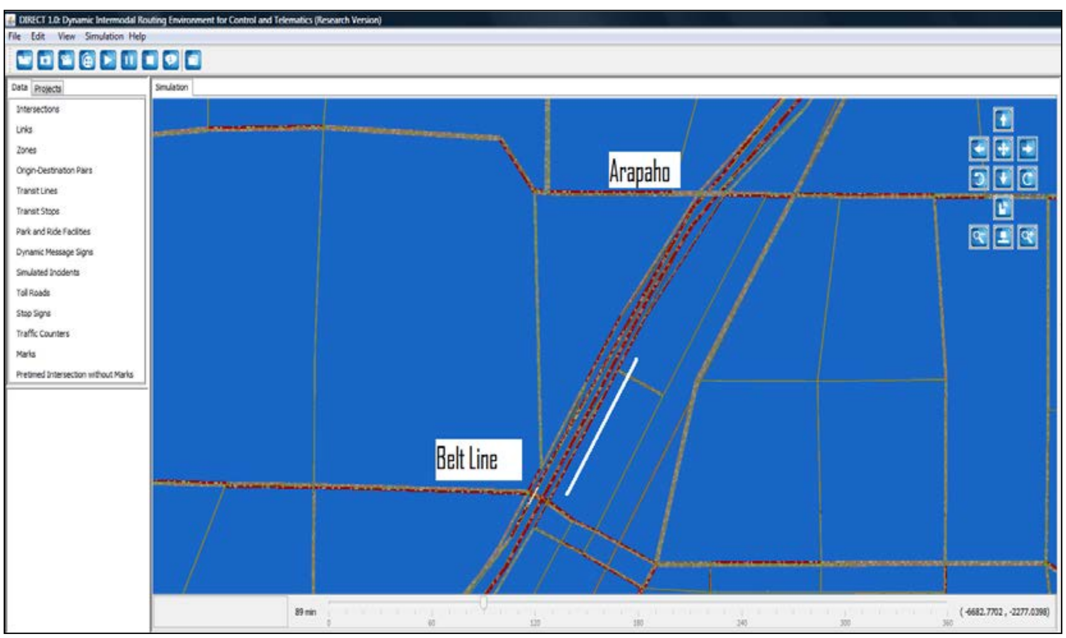
If a traveler chooses private car for the whole trip or part of it, a car is generated and moved into the network with a starting time equal to its driver starting time. Each newly generated vehicle is assigned an ID number that is unique to this vehicle. Vehicles then are moved in the network subject to the prevailing traffic conditions until they reach their final destinations or the next transfer node along the prespecified route (in the case of an intermodal trip).

If a traveler chooses a transit mode, he/she is assigned to a transit line such that the destination of this traveler is a node along the route followed by the bus line. If no single line is found or if the traveler is not satisfied with the available single line, the traveler is assigned to a path composed of two lines with one transfer node, such that the destination of the traveler is a node along the route followed by the second bus. When a transit vehicle arrives at a certain stop, all travelers waiting for a vehicle serving this specific line board this vehicle and head toward either their final destination or the next transfer node along their route.

Upon the arrival of a vehicle (private car or transit vehicle) to a certain destination node, this destination is compared to the final destinations of the travelers on board. If it matches the final destination of a traveler, the current time is recorded for this traveler as his/her arrival time. If they are different, the traveler transfers to the next transit line in his/her plan. The nearest stop is again determined and the traveler waits for his/her next transit vehicle. This process is continued until all vehicles reach their final respective destinations.

Figure 2-3 illustrates a sample of the DIRECT animation for the U.S. 75 Corridor study area.

**Figure 2-3. Extracted DIRECT Subarea Network for ICM Corridor**




[Source: Screen capture of DIRECT software Southern Methodist University.]

DIRECT uses Greenshields' flow model to relate speed, density, and flow on all links as shown in Equation 2. This formula generally describes traffic behavior, and is widely accepted and used in comparable traffic models.

$$V = \begin{cases} V_f * (1 - \frac{k}{K_{jam}})^{\alpha} & \text{if } k < K_{jam} \\ V_{\min} & \text{if } k \geq K_{jam} \end{cases}$$

Equation 2

Where:

| | | |
|---|---|---|
| $V_f$ | = | Free-flow speed; |
| $V_{min}$ | = | Minimum link speed; |
| $k$ | = | Link density; |
| $K_{jam}$ | = | Jam density; and |
| α | = | Speed-density curve shape term. |

To better reflect operating conditions on freeways, the Dallas AMS team utilized research undertaken by Professors Sia Ardekani and Shiva Nepal of the Department of Civil Engineering at the University of Texas at Arlington.[5] This research, in conjunction with the Dallas AMS' team local traffic operations knowledge, provided the initial values indicated in Table 2-1 for the Greenshields model. It is anticipated that some of these values may need to be adjusted during the calibration of the DIRECT model to reflect the nature of travel within the U.S. 75 Corridor study area. Any adjustments will be documented in a separate report describing the calibration and validation of the DIRECT model.

**Table 2-1. Initial Greenshields Model Parameters**

| Parameter | Value |
|---|---|
| $V_{min}$ | 15 mph |
| $V_f$ | 62.8 to 76.6 mph |
| $K_{jam}$ | 120.8 to 137.7 vehicles/mile/lane |
| $\alpha$ | 1 |

## Analysis of Route and Mode Shift

Future route and mode choices in the U.S. 75 Corridor will be influenced by background growth, adverse traffic conditions (e.g., incidents, heavy demand, and inclement weather), or ICM strategies (such as traveler information systems). The integrated mode-route choice in DIRECT utilizes the generalized cost function described in Equation 1 above to support comparison of multimodal alternatives. For example, travelers may choose to use transit instead of their vehicle if they receive information before their departure from home and the transit option is more attractive (i.e., the generalized cost is lower). Alternatively, if they receive en-route information of an incident, they may decide to park their car at the nearest park-and-ride lot and switch to transit. Finally, they may choose to continue driving if they receive en-route information of an incident, and they are either close to their destination or it is determined that driving to the nearest park-and-ride lot would significantly increase their generalized cost.

[5] Nepal, S. M., and S. A. Ardekani, "Traffic Flow Models for Freeway Operation," University of Texas at Arlington, October 2008.

During an incident, travelers will follow their long-term established mode-route choices *("historical routes")* unless they encounter freeway/arterial congestion or receive and consider pretrip or en-route information that may identify a more attractive mode-route option compared to the *"historical route."* Pretrip information could be in the form of a TV announcement, a PDA alert, or information provided by a web site. En-route information could be in the form of a radio announcement, a dynamic message sign (DMS), or live traffic updates via a Global Positioning System (GPS) receiver. If the ICM strategies were tested for the validation year (2007) traffic conditions, the mode-route choices from the validated DIRECT model would have been identified as the *"historical routes."* Since the ICM strategies will be assessed for future year (2011) conditions, the validated DIRECT model will be run with an adjusted demand trip table reflecting anticipated background growth to identify established mode-route choices based on these future conditions. The mode-route choices resulting from this future run will be identified as the *"historic routes"* for further evaluation of the ICM strategies. Since it is anticipated that three future demand levels (low, medium, and high) will be tested, a traveler from a specific origin to a specific destination could potentially be associated with three "*historical routes.*" This approach reflects the notion that travelers are qualitatively associating weekdays with a certain demand level, therefore, establishing a long-term mode-route choice set that includes more than one option.

During an ICM strategy assessment, travelers will be loaded from the pertinent traveler file, which includes information related to the trip start time (loading time in the simulation) and their "*historical route.*" In addition, as part of the model input, travelers are associated with three mutually exclusive groups based on their degree of access to information: 1) no information (Group A); 2) pretrip information (Group B); and 3) en-route information (Group C).

Travelers with no information will follow their "*historical routes.*" Travelers with pretrip information will have the option to update their routes at the origin of their trips. Travelers with access to en-route information could receive updates through their devices at any node along their routes, including their trip origin. Therefore, a portion of them could be considered travelers with access to pretrip information as well. As such, for modeling purposes, Group B will consider travelers with access to pretrip information ONLY, while Group C will consider travelers that have access to pretrip, as well as en-route information.

In addition to the above, 25 percent of the travelers on a freeway or arterial link will consider changing their route if they perceive that they have encountered severe congestion, where severe congestion is defined as the density of either of the two links downstream of the vehicle's current position exceeding 80 percent of the link's jam density. These travelers are picked randomly among Groups A, B, and C and constitute Group R.

Finally, any traveler associated with Groups A, B, or C could pass a DMS and be eligible to respond to the available information. As such, travelers passing a DMS sign are picked randomly among Groups A, B, and C and constitute Group DMS.

The following paragraphs provide an overview of the diversion rules for each traveler group. It should be noted that travel times associated with *"nonhistorical routes"* are based on instantaneous travel times.

- **DMS Diversion –** This type of diversion is only applicable to travelers in Group DMS. Travelers responding to a DMS compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized cost savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than a user defined threshold. Currently, DIRECT utilizes a threshold of 10 percent.

- **Pretrip Diversion –** This type of diversion is applicable to travelers in Group B. Travelers with access to pretrip information at their origin, compare the generalized cost of the suggested mode-route option to their destination with the generalized cost of their *"historical route."* Diversion occurs only if the generalized costs savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than a user defined threshold. Currently, DIRECT utilizes a threshold of 10 percent.
- **En-Route Diversion –** This type of diversion is applicable to travelers in Group C. Travelers equipped to receive en-route information compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized costs savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than a user defined threshold. Currently, DIRECT utilizes a threshold of 10 percent.
- **Congestion Diversion –** This type of diversion is only applicable to travelers in Group R. When the congestion diversion is triggered, the shortest freeway or arterial path (based on travel time and the current interval shortest path calculation) initiating from the first downstream exit (ramp or intersection) is assigned to the traveler. As such, Group R travelers' decisions are neither multimodal nor comparative.

The priority of compliance for route diversion is as follows: 1) DMS; then 2) en-route; and 3) congestion. For example, at a DMS location, if a traveler belongs to Group C, Group R, and Group DMS, it is assumed that the traveler will follow the DMS diversion rule.

In order for DIRECT to account for traveler information and model the above diversion rules correctly, each traveler with pretrip or en-route information is associated with two parameters: awareness and use. *Awareness* indicates that a traveler has access to the information (pretrip or en-route), while *use* indicates that a traveler is willing to act based on the information. Willingness does not necessarily result in an action, unless the proposed mode-route option is more attractive than the *"historical route,"* based on the diversion rules discussed above. Therefore, *use* reflects an upper bound on the percent of travelers who might divert as a response to the information, with the actual percentage dependant on the attractiveness of the new route and referred to as compliance. As an example, if 20 percent of travelers have access to pretrip information (*awareness*), and of that subgroup 15 percent are willing to act on that information (*use*), then the maximum compliance would be three percent of the total traveler population.

As discussed in Section 3.2, based on the 2005 Perception Tracking survey conducted in Minneapolis, 61 percent of travelers are aware of pretrip information but only 15 percent make use of the information. Based on the pretrip diversion rule discussed above, the compliance could be up to 15 percent, depending on the percent of travelers that find the generalized cost savings to be more than 10 percent.

While DMS is a form of en-route information, it presents a special case in the current version of DIRECT, where *awareness* and *use* are collapsed under the *use* parameter (i.e., it is assumed that 100 percent of the travelers have access to the information presented in the DMS). Currently, the default *use* value in DIRECT is 75 percent.

## 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). 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.

The use of microsimulation modeling was initially considered for assessing arterial traffic signal coordination. There are two partial VISSIM networks available in the study area: one is near downtown Dallas (with 200 traffic signals), and the second is near the LBJ Interchange north of downtown. Neither of these networks covers the arterial segments parallel to the incident location considered for testing on U.S. 75. Therefore, given the ability of DIRECT to reflect signal timings, it was decided not to incorporate the VISSIM models in the current Analysis Plan.

# Chapter 3. Analysis Scenarios and ICM Strategies

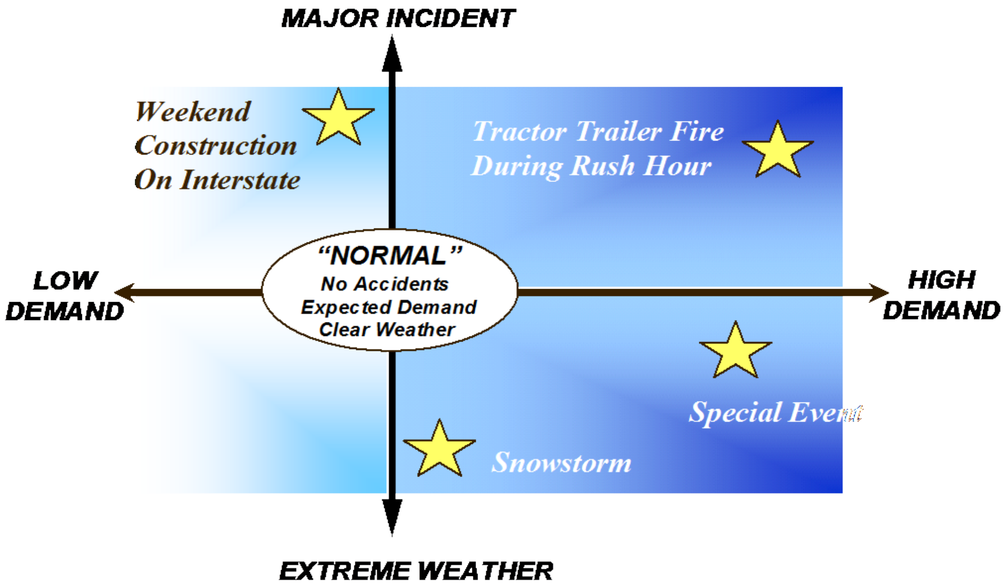
This section provides an overview of priority ICM strategies for the U.S. 75 Corridor, and the scenarios that will be studied to analyze the impacts of these strategies. The analysis will assist local agencies to:

- **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 U.S. 75 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. Figure 3-2 shows the relative frequency of nonrecurrent conditions based on archived traffic conditions.

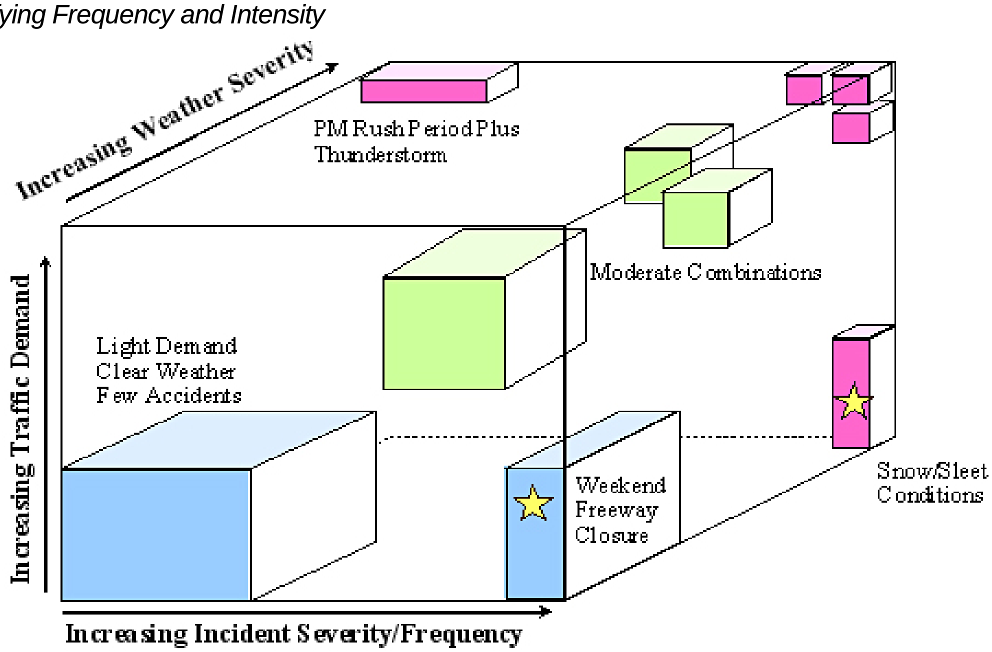
**Figure 3-1. Key ICM Impacts May Be Lost If Only "Normal" Conditions Are Considered**




[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/).]

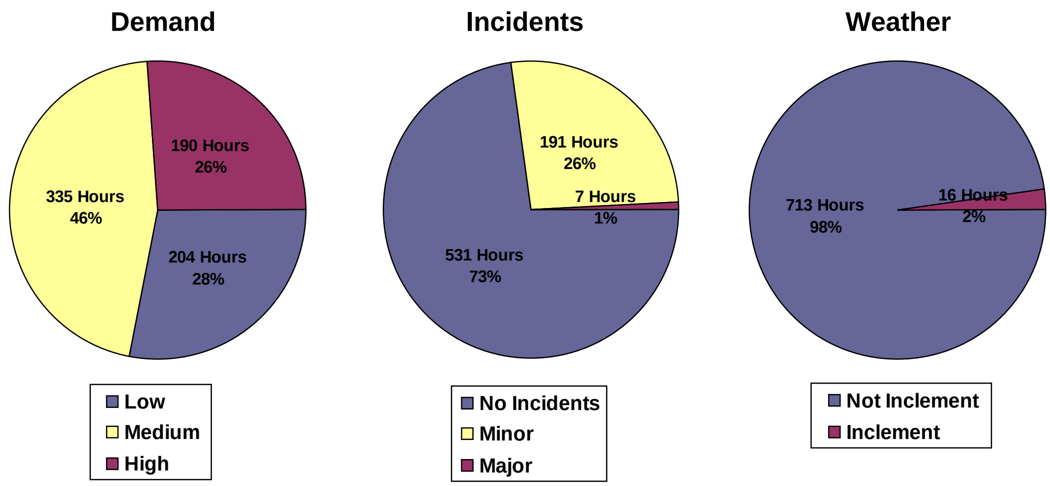
The Dallas AMS team conducted a cluster analysis to examine the impacts of demand, incidents, and weather conditions on morning peak-period travel, with an overall objective of determining the percent of "normal" days. The analysis examined year 2007, weekday hourly travel data from 6:00 a.m. to 9:00 a.m., on southbound U.S. 75, excluding days where detectors produced incomplete or insufficient data (e.g., the detector was malfunctioning or data was not available for all hours working, etc.). The following definitions were established for the basis of conducting the cluster analysis:

- **Travel Demand –** High demand is defined as greater than 7,500 vph, medium demand is between 6,900 and 7,500 vph, and low demand is less than 6,900 vph.
- **Incidents –** A major incident is defined as two or more general-purpose lanes affected, while a minor incident is defined as one general-purpose lane (or one general-purpose lane and shoulder) affected.
- **Weather –** Inclement weather is defined as raining more than 0.1 inch per hour, or having conditions of ice or snow.

The results of the cluster analysis are shown in Figure 3-3 and Table 3-1. Figure 3-3 illustrates the individual impacts of demand, incidents, and weather conditions on weekday morning peak-period travel on southbound U.S. 75, while Table 3-1 shows the cumulative impacts of these conditions.

**Figure 3-3. Cluster Analysis for U.S. 75 Dallas**

Southbound Direction




Note: Cluster analysis conducted for Year 2007, Weekday, 6:00-9:00 a.m., southbound direction only. Historical weather data obtained from http://www.weatherunderground.com. Incident and demand data obtained from DalTrans Traffic Management Center. Incident data includes accidents, minor breakdowns, debris, etc.

**Table 3-1. Distribution of Operating Conditions in U.S. 75 Dallas**

| Demand | Incident | Inclement Weather | Number of Hours | Percent |
|---|---|---|---|---|
| Med | No | No | 247 | 33.9% |
| Low | No | No | 136 | 18.7% |
| High | No | No | 134 | 18.4% |
| Med | Minor | No | 79 | 10.8% |
| High | Minor | No | 55 | 7.5% |
| Low | Minor | No | 55 | 7.5% |
| Low | No | Yes | 9 | 1.2% |
| Med | No | Yes | 5 | 0.7% |
| Med | Major | No | 4 | 0.5% |
| Low | Major | No | 2 | 0.3% |
| Low | Minor | Yes | 2 | 0.3% |
| High | Major | No | 1 | 0.1% |
| Med | Minor | Yes | 0 | 0.0% |
| High | No | Yes | 0 | 0.0% |
| High | Minor | Yes | 0 | 0.0% |
| High | Major | Yes | 0 | 0.0% |
| Med | Major | Yes | 0 | 0.0% |
| Low | Major | Yes | 0 | 0.0% |

In the ICM Concept of Operations (ConOps) report, the Dallas AMS team identified a variety of scenarios to illustrate the impacts of full ICM implementation. The scenarios reflect major or minor incidents on the freeway and arterial network within the ICM Corridor study, as well as special situations such as a special event (e.g., Texas State Fair) and an inclement weather event. Modeling the a.m. inbound peak-period is not conducive to modeling special event scenarios, since the special events that attract large volumes of traffic arriving at a fixed start time 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, and currently there is no such data available for special events.

In addition, in terms of weather events, the year 2007 cluster analysis undertaken for the morning peak-period for U.S. 75 found that very few days included inclement weather (i.e., approximately two percent). Therefore, in the interest of dedicating modeling time where it will be most efficient, the Dallas AMS team has decided to exclude special event and weather-related scenarios from the AMS efforts. Table 3-2 summarizes the revised cluster analysis.

**Table 3-2. Revised Distribution of Operating Conditions in U.S. 75 Dallas**

| Demand | Incident | Number of Hours | Percent |
|---|---|---|---|
| Med | No | 252 | 34.6% |
| Low | No | 145 | 19.9% |
| High | No | 134 | 18.4% |
| Med | Minor | 79 | 10.8% |
| Low | Minor | 57 | 7.8% |
| High | Minor | 55 | 7.5% |
| Med | Major | 4 | 0.5% |
| Low | Major | 2 | 0.3% |
| High | Major | 1 | 0.1% |

During a meeting of the U.S. Department of Transportation (DOT) and the Dallas AMS team, it was requested for the purposes of the study, that the remaining scenarios and their associated strategies be ranked from low to high priority. Based on this exercise, the following scenarios and their associated probability of occurrence were identified for analysis:

1. **Daily Operations (No Incident) – High Demand.** This scenario with good weather and no incidents represented approximately 18.4 percent of the morning peak-period hours of year 2007. High demand was defined as a volume of greater than 7,500 vehicles per hour in the peak direction (four lanes of capacity in the peak direction).
2. **Daily Operation (No Incident) – Medium Demand.** This scenario represented 34.6 percent of the morning peak-period hours of year 2007.
3. **Daily Operation (No Incident) – Low Demand.** This scenario represented 19.9 percent of the morning peak-period hours of year 2007.
4. **Minor Freeway Traffic Incident – High Demand.** This scenario represented 7.5 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
5. **Minor Freeway Incident – Medium Demand.** This scenario represented 10.8 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
6. **Minor Freeway Incident – Low Demand.** This scenario represented 7.8 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
7. **Major Freeway Traffic Incident – High Demand.** This scenario represented less than one percent of the morning peak-period hours of year 2007. A major incident was defined as an incident that closed two or more freeway lanes, and impacted traffic operations for an hour or more.
8. **Major Freeway Incident – Medium Demand.** This scenario represented less than one percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
9. **Major Freeway Incident – Low Demand.** This scenario represented less than one percent of the morning peak-period hours of year 2007. A major incident was defined as an incident that closed two or more freeway lanes, and impacted traffic operations for an hour or more.

In addition, the Dallas AMS team was interested in examining two different incident locations under the minor incident scenario and two different incident severities (i.e., number of lanes blocked) under the major incident scenario. The matrix shown in Table 3-3 summarizes the freeway operating scenarios to be modeled, along with their characteristics and associated probabilities. The sum of the freeway operating scenario probabilities is 100 percent, and it is assumed that the probability for a minor incident with medium or high demand is the sum of the probabilities for this type of incident at two locations. Similarly, the probability for a major incident with medium or high demand is the sum of the probabilities for this type for two operating conditions (i.e., two lanes versus three lanes blocked).

**Table 3-3. Freeway Operating Scenarios**

| | No Incident | | | Minor Incident | | | | | Major Incident | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand | Low | Med | High | Low | Med | Med | High | High | Low | Med | Med | High | High |
| Scenario No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Incident Duration | NA | NA | NA | 45 min | 45 min | 45 min | 45 min | 45 min | 1 hour | 1 hour | 1 hour | 1 hour | 1 hour |
| No. of Lanes Blocked | NA | NA | NA | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 2 | 3 |
| Incident Location | NA | NA | NA | Belt Line Road | Belt Line Road | Forest Lane | Belt Line Road | Forest Lane | Belt Line Road | Belt Line Road | Belt Line Road | Belt Line Road | Belt Line Road |
| Incident Start Time | NA | NA | NA | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. | 7:00 a.m. |
| Probability | 19.9% | 34.6% | 18.4% | 7.8% | 5.4% | 5.4% | 3.75% | 3.75% | 0.3% | 0.25% | 0.25% | 0.05% | 0.05% |
| No. of Runs Pre-ICM (13) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| No. of Runs Post-ICM (44) | 0[a] | 3[b] | 3[b] | 0[a] | 3 | 3 | 3 | 3 | 2 | 6 | 6 | 6 | 6 |
| Total No. of Runs (57) | 1 | 4[b] | 4[b] | 1 | 4 | 4 | 4 | 4 | 3 | 7 | 7 | 7 | 7 |

[a] Scenario 1 (No incident, low demand) and Scenario 4 (Minor Incident, low demand) will use the “Pre-ICM” run results for the “Post-ICM” cases.

[b] HOT lane and Express Toll lane operation are not considered ICM strategies. The U.S. 75 team will make these additional runs to see the benefit of these managed lane strategies for medium and high demand.

## 3.2 ICM Strategies

Travelers have multiple possible responses to congestion and mitigating ICM strategies: route diversion, temporal diversion, mode change, changing travel destination, or canceling their trip are some of these traveler responses. The U.S. 75 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 will reflect year 2007 operating conditions (which do not include HOV operations). The Future Baseline Scenario will be modeled using information for year 2011, and will include the HOV lane.

The Dallas AMS team provided a cross-tabulation between anticipated ICM strategies and the scenarios identified above. The following list identifies the strategies associated with the high-priority scenarios, while Table 3-4 identifies their applicability with each of the abovementioned scenarios:

- Comparative travel time information (pretrip and en-route);
- Incident signal retiming plans for arterials;
- Incident signal retiming plans for frontage roads;
- Light-Rail Transit (LRT) smart parking system;
- Red Line capacity increase;
- LRT station parking expansion (private parking); and
- LRT station parking expansion (valet parking).

In addition, the Dallas AMS team also is interested in examining how the two following managed lane strategies will affect corridor operations:

- High-Occupancy Toll (HOT) lane with HOV 2+ free (congestion pricing); and
- HOV Express Lane (HOV 2+ one-half price with congestion pricing).

A key in implementing any ICM strategy is disseminating good quality, comparative travel time data to each of the ICM partner agencies. The stakeholders in the ICM Corridor are implementing a data sharing tool that will allow for real-time dissemination of incident information and comparative travel time information for freeways, frontage roads, arterials, and LRT lines. This will initially be deployed as a stand-alone application that each transportation management center will run.

The strategies listed above are discussed in more detail in the ensuing sections**.** Appendix A provides additional details reflecting pre- and post-ICM implementation for each ICM strategy, as well as expected model outputs. Daily Operations (No-Incident) and Minor Incidents associated with low demand will be analyzed for the post-ICM conditions. For purposes of computing performance measures, the statistics from the pre-ICM analysis will be utilized.

**Table 3-4. Summary ICM High-Priority Strategies for U.S. 75**

| Scenario | Daily Operations – No Incident | | Minor Incident | | Major Incident | | |
|---|---|---|---|---|---|---|---|
| Demand | Med | High | Med[c] | High[c] | Low[d] | Med[d] | High[d] |
| *Traveler Information* | | | | | | | |
| Comparative, multimodal travel time information (pretrip and en-route) | ● | ● | ● | ● | ● | ● | ● |
| *Traffic Management* | | | | | | | |
| Incident signal retiming plans for frontage roads[a] | | | ● | ● | ● | ● | ● |
| Incident signal retiming plans for arterials[b] | | | ● | ● | ● | ● | ● |
| *Managed Lanes* | | | | | | | |
| HOV lane[c] | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| HOT lane (congesting pricing)[d] | ● | ● | | | | | |
| Express toll lane (congestion pricing)[d] | ● | ● | | | | | |
| *Light-Rail Transit Management[e]* | | | | | | | |
| Smart parking system | | | | | | ● | ● |
| Red line capacity increase | | | | | | ● | ● |
| Station parking expansion (private parking) | | | | | | ● | ● |
| Station parking expansion (valet parking) | | | | | | ● | ● |

[a] The frontage road retiming plan could run as an individual traffic management strategy for minor incidents.

[b] The traffic management strategies (frontage road timing and arterial timing) are combined and not run as separate strategies for a major incident.

[c] HOV lane 2+ currently is in operation, thus is not considered an ICM strategy, but is part of all scenarios.

[d] HOT/Express toll lanes also are not considered ICM strategies. The U.S. 75 team would like to see the benefit of these managed lane strategies for medium and high demand.

[e] The LRT Smart Parking System strategy is always conducted with the other three transit management strategies. Private and valet parking expansion will not be implemented as a combined strategy.

# Traveler Information

***Comparative Travel Times (Mode and Route)***

Multimodal information dissemination will include travel time comparisons for freeway, arterial, and transit to provide travelers with information on the best routes and modes. The information also will include park-and-ride availability. As a result, it is anticipated that more travelers will choose the best option (alter route, mode, and departure time) that reflects the optimal path. The comparative travel time information will be distributed pretrip and en-route.

***Pretrip Traveler Information***

Pretrip information includes any traveler information accessible to the public that can be used in planning trip routes, estimating departure times, and/or choosing a travel mode. Such information can be available through the agency web sites, a 511 system, public access television (TV), local radio, and other media. The analysis will capture the impacts of such information on traveler's route choice, departure times, and/or choice of travel mode. In the base year of 2007, only the southern section of the freeway corridor was instrumented with detectors and closed-circuit television (CCTV) cameras for incident detection and verification. The lack of ITS in the middle and northern sections has made incident detection and verification difficult for the Texas Department of Transportation (TxDOT). Nevertheless, full instrumentation of the corridor is operational in 2009 and is anticipated to result in earlier detection, verification, and dissemination of traveler information. Data from current traveler information indicates that posting of incidents and pretrip notification to travelers can be delayed up to 30 minutes from when the incident actually occurred.

Based on the 2005 Perception Tracking survey conducted in Minneapolis, 61 percent of travelers are aware of pretrip information and 15 percent will make use of it. Given that limited data exists on the percentage of U.S. 75 travelers who access such information and are willing to act on it (i.e., divert from their "historical routes") prior to making their trips, the Dallas AMS team will utilize awareness and use values similar to the Minneapolis study. The ITS system in the U.S. 75 corridor is still in development, thus the Dallas AMS team proposes 60 percent *awareness* and 10 percent *use* for the pre-ICM scenarios. In the post-ICM scenarios, the Dallas AMS team expects *awareness* to increase as 511 and more valuable traveler information is deployed (U.S. comparative travel times). Therefore, the Dallas AMS team proposes 80 percent *awareness* and 20 percent *use*. Travelers with pretrip information have the capability to update their routes only at the origin of their trips. As such, the generalized cost of the available mode-route options will be calculated in the beginning of their trip, and if an option is more attractive compared to the *"historical route,"* that option will be selected (see Section 2.2 for additional details).

Given the relationship of travelers with access to pretrip and en-route information in DIRECT (see Section 2.2), 10 percent (out of the 60 percent) in the pre-ICM scenario will be considered travelers with access to pretrip information ONLY (Group B). The remaining 50 percent will reflect travelers that have access to en-route information also (Group C). For the post-ICM scenario, the corresponding percentages will be 20 and 60 percent for Groups B and C, respectively.

### *En-Route Traveller Information*

One of the ICM strategies is to proactively disseminate en-route information via 511, radio/TV, agency Internet sites, GPS devices, etc. Discussions with U.S. DOT and the Dallas AMS team have revealed that there is a need to model the impact of en-route 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, 511, GPS devices or information provided by a DMS sign.
2. **Change in mode en-route.** The possibility of changing mode while en-route has potential on the U.S. 75 Corridor, considering that there are a number of park-and-ride facilities. An SOV traveler may receive en-route traveler information of congested conditions on U.S. 75 and park-and-ride availability at the stations along the DART Red line. DMS message information may be simple with incident information and which park-and-ride station to use, while other media may provide more detail about the incident, actual number of park-and-ride lots spaces available, and comparative travel time information.

In general, en-route information will be provided by either a DMS sign or traveler information media that can range from radio to GPS devices. The 2005 Minneapolis Perception Tracking survey indicated that 72 percent of the drivers have seen a sign (*awareness*), but only 29 percent alter their route based on the available information (*use*). For a DMS, the Dallas AMS team will utilize a 60 and 75 percent *use* and a target compliance of 20 and 30 percent[6] for the pre-ICM and post-ICM scenarios, respectively. Since there was no data related to en-route traveler information media, the Dallas team will utilize 50 percent *awareness* and 20 percent *use* for the pre-ICM scenarios. For the post-ICM scenarios, *awareness* will increase to 60 percent and *use* to 30 percent. These *awareness* percentages are consistent with the discussion above related to travelers with pretrip information.

## Incident Signal Retiming

The various stakeholders will develop 'flush' signal timing plans to increase arterial capacity and decrease arterial travel time during an incident. The anticipated 15 percent increase in capacity (on both the frontage road and strategic arterial) will be reflected in DIRECT in the form of signal retiming. Southbound phases will have the green time phases increased to allow for more capacity along those routes.

### *Frontage Road Signal Retiming*

For a minor incident, signal retiming adjustments may suffice on the frontage roads only. By giving more green time to the southbound movements on the frontage road, freeway travelers can detour to the frontage road upstream of an incident and return to the freeway downstream of the incident.

*Arterial Street Signal Retiming/Coordination*

In addition to the frontage road signal retiming, signal retiming and signal coordination to a strategic arterial may increase corridor capacity. The stakeholders have identified Greenville Avenue as the

[6] The target compliance is established to provide a benchmark of performance for DIRECT, given the high use associated with a DMS. In the event the compliance value produced by DIRECT exceeds the target or seem inconsistent with the anticipated operating conditions at the DMS location, the Dallas AMS team could reevaluate the 10-percent threshold associated with the DMS diversion rule.

primary arterial for diverted freeway traffic, since it runs parallel to U.S. 75 for nearly the entire length of the freeway corridor and it also is the closest major arterial with available capacity. This strategy will always run in combination with the frontage road signal retiming, and will include increasing green time to the southbound movements along Greenville Avenue. Signal offsets also may be adjusted, as needed and where warranted.

## Managed Lanes

### *Congestion Pricing*

Currently, the U.S. 75 HOV lanes are at approximately 80 percent of capacity in the peak hour under their current HOV 2+ operation. There is significant capacity available in the off-peak-period and direction of travel. HOV lanes in the Dallas region do not yet use dynamic pricing (i.e., setting toll rates based on the changing level of traffic congestion). The impacts of different levels of congestion on toll prices and subsequently on traffic management on the corridor will be evaluated in the HOT/ HOV lane scenarios.

Dynamic pricing for the region currently is being developed for another project in the Dallas area. The proposed dynamic pricing algorithm for U.S. 75 is consistent with the regional strategies of maintaining 50 mph (LOS d) on managed lanes. The algorithm is based on how density of the HOT lane changes over time. Density is calculated every minute from ITS detectors on the HOT lane. Every five minutes, the dynamic pricing algorithm compares the current density with the density needed to maintain a speed of 50 mph. If the lane is operating below a density associated with 50 mph, then the price will not be adjusted. If the density on the HOT lane exceeds the density associated with 50 mph, then the price is increased one toll increment (the toll increment is equal to the current toll rate of $0.145 per mile). If the density stays above the 50 mph threshold, then the price continues to increase one toll increment until the density drops below the threshold. If the density drops below the lower threshold (i.e., density associated with LOS C or better), then the price is reduced by one toll increment. For modeling purposes, the DIRECT model will calculate density of the HOT lane at each path update interval (i.e., every five minutes), and select the toll price from a look-up table based on the rules described above.

### *HOT Lane*

The first “strategy” to be tested is how congestion pricing would improve utilization of the HOT lane and improve overall corridor operations if SOVs were allowed to use the lane for a toll. HOV 2+ users would still be allowed to use the lane for free, but SOVs would be given the choice to use the lane for the assigned toll. The toll would be set by the dynamic pricing algorithm. Note that HOT lane is not considered an ICM strategy, but the Dallas AMS team would like to see the potential benefits of this managed lane concept.

### *Express Toll*

The second “strategy” for managed lanes is to test an express toll lane concept, where HOV 2+ occupancy vehicles pay one-half of the dynamically priced toll, while SOVs pay the full dynamically priced toll. This is the current practice being implemented on long-term, managed lanes being constructed in the region. Note that express toll lane is not considered an ICM strategy, but the Dallas AMS team would like to see the potential benefits of this managed lane concept.

## Parking Availability at Red Line Park-and-Ride Lots

For the mode shift strategies, parking at the Red Line Light Rail (LRT) park-and-ride lots is critical to encourage changes in travelers' behavior. The DART park-and-ride lots toward the north end of the Red Line currently are at capacity, with station parking often taking place on adjacent city streets. However, DART recently expanded the Parker Road and the President George Bush Turnpike (PGBT) stations, which will provide needed capacity for future ICM strategies. There are three strategies that will be implemented related to parking at these park-and-ride lots.

### *Smart Parking*

The first parking strategy is to implement Smart Parking systems at each of the DART park-and-ride lots on the Red Line along U.S. 75. This will be a basic system that continuously collects vehicle counts entering and leaving the lot, and records the number of parking spots available. By disseminating information regarding park-and-ride lot availability, traveler's confidence in transit is expected to increase, and potential modal shifts may occur during incidents. DMS message information will indicate which park-and-ride station to use. Internet, TV, and radio information may include more detail about the actual number of park-and-ride lots spaces available at each station. In DIRECT, the parking lot capacity will be kept at five percent below the actual lot capacity in the pre-ICM scenario. When the lot reaches this threshold, paths with park-and-ride will not be allowed. Currently, lot operators try to keep a buffer of spaces to make sure everyone has enough spaces. With ICM and Smart Parking, DIRECT will allow the lot to reach full capacity before the park-and-ride lot paths are excluded from the route and mode selection. Since this strategy will augment the other parking strategies, it will always be used in combination with one of the two strategies.

### *Private Parking*

The second strategy is to implement station parking expansion by forming public-private partnerships with parking owners near DART LRT stations. DART will establish agreements with these private parking owners for use of their parking facilities, either on a daily basis or during peak parking times. By utilizing this private overflow parking, more transit passengers can be accommodated at the stations. DART will need to provide shuttle service from these private lots to the LRT stations.

### *Valet Parking*

The third strategy is to implement station parking expansion with valet service for parking. This is a service that has been introduced at the DFW International Airport. For the U.S. 75 Corridor, the plan would be to implement the service at one of the strategic park-and-ride lots (i.e., PGBT Station). Valet parking service would reduce the transfer time at the station, and increase the utility of using LRT transit for mode-shift strategies.

## Red Line Capacity Increase

DART has the capability of adding capacity to the Red Line through additional train cars or through decreased headways. Under major corridor incidents, it may be beneficial to decrease headways of the Red Line to increase the person carrying capacity of the LRT system. As part of the ICM strategy, it is anticipated that headways will be decreased from 10 minutes to 7.5 minutes.

## 3.3 Summary of Analysis Settings

The goal of the ICM alternatives analysis for the U.S. 75 Site is to determine under which incident and demand conditions a given strategy has the potential to benefit the corridor. Thus, the analysis settings revolve around severity and location of an incident under various demand settings. The number of ICM strategies and scenarios involved in the Analysis Plan make it imperative to analyze only one peak-period in order to stay within the schedule and budget constraints. Based on discussions between the U.S. DOT AMS team and the Dallas team, the a.m. peak-period was selected for analysis.

The Dallas AMS team has considered how the strategies should be coordinated to provide the greatest impact on the U.S. 75 corridor. Under traveler information strategies, there is only one strategy of offering comparative travel time. The comparative travel time strategy will be run isolated and in conjunction with other traffic management and transit management strategies.

Under the traffic management strategies, alternate timing plans will be investigated for both the U.S. 75 frontage roads and Greenville Avenue, which is a strategic arterial. Under a minor incident, the stakeholders are interested in how a strategy with just frontage roads compares to a strategy with both frontage roads and Greenville Avenue to improve corridor operations. For a major incident, it is assumed that both strategies are needed; and thus, the traffic management scenarios will always include both frontages roads and Greenville Avenue.

Under managed lane strategies, HOV lane 2+ currently is in operation on U.S. 75; and thus, this configuration is not considered an ICM strategy, but is part of all scenarios. HOT/Express Toll Lanes also are not considered ICM strategies. The U.S. 75 team would like to see the benefit of these managed lane strategies for medium and high demand. The Dallas AMS team would like to investigate both a HOT lane and an Express Toll lane under medium and high demand. These two configurations would never be run concurrently.

Under transit management strategies, there are four strategies. The LRT Smart Parking System strategy is a foundational element that provides information on parking availability; and thus always will be paired with the other three transit management strategies. The Dallas AMS team is interested in the benefits of adding LRT capacity, private parking, and valet parking. Each of these three strategies will be tested individually (with the Smart Parking System). The one combined transit management strategy will include adding LRT capacity and private parking (along with the Smart Parking System). The private parking was selected over the valet because it is perceived to have lower operation and maintenance costs to the transit agency. Private and valet parking expansion are considered mutually exclusive, and will not be implemented as a combined strategy.

In summary, the strategies applied to the scenarios have been selected based on the potential to provide the greatest benefit to travelers in the U.S. 75 corridor. Not all the combination of strategies can be tested within the scope of Stage 2; and thus, the stakeholders have matched strategies to the scenarios based on the potential to improve vehicle and person carrying capacity. The Stage 2 results should provide valuable input to the Dallas AMS team in developing the decision support system for the Stage 3 Demonstration project. Stage 2 will show under which demand and incident scenarios the ICM strategies will have the greatest benefit. These results can assist in developing sets of rules for the expert system. Table 3-5 summarizes the anticipated analysis settings for the U.S. 75 Corridor.

**Table 3-5. Dallas U.S. 75 Corridor – Summary of Analysis Settings**

| Parameter | Value | Comment |
|---|---|---|
| Base year | 2007 | • The analysis will be based on data from the available validated regional travel demand model. |
| Analysis year | 2011 | • The analysis year corresponds with the anticipated implementation year. |
| Time period of analysis | a.m. | • The analysis of the a.m. peak-period allows assessment of the proposed route and mode shift ICM strategies. |
| Simulation period | 5:30 hrs | • 5:30 a.m. to 11:00 a.m.; peak-period 6:30 a.m. to 9:00 a.m. |
| Freeway incident location # 1 | Belt Line Road | • Location used for Known Incident validation based on cluster analysis and crash report. This location impacts the cities of Richardson and Plano. |
| Freeway incident location # 2 | Forest Lane | • This location also will impact City of Dallas and is closer to the interchange at IH 635 where there is a high frequency of incidents. |
| Incident duration | Start time and clearance time | • See Table 3-3 for details. |
| Number of scenarios | 13 | • Ten freeway incident and three no incident (see Table 3-3). |
| Anticipated number of runs (Post-ICM) | 44 | • Eleven individual strategy runs (11 runs for Traveler Information for No-Incident and Incident scenarios).<br>• Four combined Traveler Information and Traffic Management (Frontage road retiming) strategy runs.<br>• Nine combined Traveler Information and Traffic Management strategy (Frontage road and Arterial) runs for Minor and Major Incidents.<br>• Four combined Traveler Information, Traffic Management and Transit Management (Smart Parking and Red Line capacity increase) strategy runs for Major Incidents.<br>• Four combined Traveler Information, Traffic Management and Transit Management (Smart Parking and Increase Station Parking Capacity with Private Parking) strategy runs for Major Incidents.<br>• Four combined Traveler Information, Traffic Management and Transit Management (Smart Parking and Increase Station Parking Capacity with Valet Parking) strategy runs for Major Incidents. |

**Table 3-5. Dallas U.S. 75 Corridor – Summary of Analysis Settings (continued)**

| Parameter | Value | Comment |
|---|---|---|
| Anticipated number of runs (Post-ICM) (continued) | | • Four combined Traveler Information, Traffic Management and Transit Management (all transit management strategies except for Increase Station Parking Capacity with Valet Parking) strategy runs for Major Incidents.<br>• Four Daily Operations – No Incident runs with Traveler Information and HOT lane or Express lane. |
| Anticipated number of runs (Pre-ICM) | 13 | • Thirteen freeway incident scenarios, each reflecting combination of demand levels and strategies currently in place (see Table 3-3). |

## 3.4 Data Requirements

The following is information on available data that will be utilized to finalize and implement the analysis of U.S. 75 ICM strategies and scenarios. This list represents our current understanding of the available data, and additional information may be needed as the modeling effort moves forward as identified in the Data Collection Plan.

- Freeway and arterial speed and volume data;
- Skycomp Aerial survey identifying queues on selected roadways;
- DMS locations;
- HOV lane data (speed, volume);
- Signal timing plans for the arterial intersection in the defined ICM Corridor;
- Transit data (bus and rail routes, frequencies, stops or terminal locations, park-and-ride capacities and utilization, and rail car capacity);
- NCTCOG Travel Demand Model roadway networks and socioeconomic data;
- DART On-Board survey;
- Utilization of spaces at DART parking lots and surrounding on-street parking; and
- Bus and LRT ridership counts.

# 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 U.S. 75 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 U.S. 75 Corridor for short- and long-term implementation.

In the Concept of Operations, the Dallas AMS team defined four overall goals for the U.S. 75 ICM initiative, as summarized below.

- **Goal 1 – Increase corridor throughput.** The U.S. 75 ICM initiative will optimize the overall throughput of the corridor by managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks.
- **Goal 2 – Improve travel time reliability.** The transportation agencies within the corridor will provide a multimodal transportation system that adequately meets customer expectations for travel time predictability.
- **Goal 3 – Improve incident management.** Provide a corridor-wide and integrated approach to the management of incidents, events, and emergencies that occur within the corridor; or that otherwise impact the operation of the corridor, including planning, detection and verification, response, and information sharing, such that the corridor returns back to "normal."
- **Goal 4 – Enable intermodal travel decisions.** Travelers must be provided with a holistic view of the corridor and its operation through the delivery of timely, accurate, and reliable multimodal information, which then allows travelers to make informed choices regarding departure time, mode, and route of travel.

Based on the goals identified by the Dallas AMS team and the objectives of the U.S. DOT ICM project, a set of performance measures will be developed to assess the various scenarios and strategies. The performance measures will focus on the following four key areas:

1. **Mobility –** Describes how well the corridor moves people and freight;
2. **Reliability and Variability –** 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, developed guidance for mobility and reliability performance measures utilizing outputs from the simulation models. The following sections provide an overview of the areas the selected performance measures will address, while Appendix B provides the U.S. DOT guidance.

## 4.1 Mobility

Mobility describes how well the corridor moves people and freight. The mobility performance measures are readily forecast. Three primary types of measures will be used to quantify mobility in the U.S. 75 Corridor, including the following:

1. **Travel time –** This is defined as the average travel time for the entire length of the corridor or segment within a study corridor by facility type (e.g., mainline, HOV, local streets, and transit) and by direction of travel. Travel times will be computed for the peak-period.
2. **Delay –** This is defined as the total observed travel time less the travel time under uncongested conditions, and will be reported both in terms of vehicle-hours and person-hours of delay. Delays will be calculated for freeway mainline and HOV facilities, transit, and surface streets.
3. **Throughput** – This is defined as both vehicle and person per hour by direction. The measure will be reported for both the freeway (general-purpose lanes, HOV, and frontage roads) and for the entire corridor (general-purpose lanes, HOV, frontage roads, strategic arterials, and LRT line).

## 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 mobility varies from day to day. For the U.S. 75 Corridor, travel time reliability/variability will be calculated using the simulation models by performing multiple model runs for all scenarios. Appendix B describes the methodology used in calculating reliability and variability impacts.

## 4.3 Safety

To estimate safety benefits, a set of default national crash rates was obtained from the FHWA’s ITS Deployment Analysis System (IDAS) tool. Crash rates are stratified into fatal accidents, injury accidents, and property damage only (PDO) accidents, and are applied based on roadway vehicle miles traveled (VMT). Different rates are available for freeway links versus arterial links, with greater crash risks for arterial roadways. Only the freeway rates will be applied in the AMS analysis. Further, the rates for injury and PDO crashes increase in relation to increased congestion (as measured by volume-to-capacity (V/C) ratio for the roadway section).[7]

In order to better configure the default national rates to the local conditions, the default rates were compared with local crash data compiled by the TxDOT Crash Records Information System (CRIS). The overall default IDAS crash rate across all accident types equates to 1.21 crashes per million VMT.

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

This rate was compared with an average rate of 1.20 crashes per million VMT, as observed on Texas urban freeways during the years 2005 to 2007.[8] This comparison revealed that the observed crash rate (for urban freeways) in Texas is 99.3 percent of the national rate. This factor and the ones listed in Table 4-1 were used to adjust the national crash rates downward to more appropriately reflect local conditions, yet still maintain the predictive ability of the national rates to estimate changes in crashes based on changes in congestion levels.

**Table 4-1. National Versus Texas Crash Rate** (Crashes per Million VMT)

| Crash Rate | Total Crash Rate | Fatality Crash Rate | Injury Crash Rate | PDO Crash Rate |
|---|---|---|---|---|
| National | 1.2100 | 0.0066 | 0.7060 | 0.9192 |
| Texas | 1.2013 | 0.0066 | 0.5122 | 0.6826 |
| Texas as percent of U.S. | 99.28% | 99.28% | 72.55% | 74.26% |

Applying the respective adjustment factors results in the injury rates and PDO rates as presented in Table 4-2. Note the fatality crash rate of 0.0066 does not vary by the V/C ratio.

**Table 4-2. Injury and PDO Crash Rates from IDAS** (Crashes per Million VMT)

| V/C Ratio | Default Freeway Injury Rates | Adjusted Freeway Injury Rates | Default Freeway PDO Rates | Adjusted Freeway PDO Rates |
|---|---|---|---|---|
| < 0.09 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.19 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.29 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.39 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.49 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.59 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.69 | 0.4763 | 0.3455 | 0.6171 | 0.4583 |
| 0.79 | 0.5318 | 0.3858 | 0.7183 | 0.5334 |
| 0.89 | 0.5318 | 0.3858 | 0.7183 | 0.5334 |
| 0.99 | 0.6770 | 0.4911 | 0.8365 | 0.6212 |
| 1.00 | 0.7060 | 0.5122 | 0.9192 | 0.6826 |

8 *Traffic Safety Fundamentals Handbook*, Minnesota DOT Office of Traffic, Safety and Technology, August 2008.

The analysis will result in an estimated number of crashes (by severity) occurring under each scenario.[9] The number of crashes will then be multiplied with the probability associated with each individual scenario to estimate the predicted crashes for the pre- and post-ICM runs. 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. Similar analysis methodologies are being conducted at other ICM sites, and will allow these rates to be reasonably configured to the local conditions at each site while still producing comparable findings.

## 4.4 Emissions and Fuel Consumption

The U.S. 75 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.

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

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 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 field 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 variable message sign locations, incremental costs of Red Line parking management, etc.); and added to the infrastructure costs to determine the total estimated cost of the deployment.

## 4.6 Local Measures

The Dallas AMS team also is interested in measuring the revenue expected to be generated by any of the HOT lane or Express Toll lane options. The region has adopted an excess revenue policy which states that O&M costs must be retired before any revenue is classified as excess. The DIRECT model can track the number of vehicles that use the HOT lane (by link) and the toll "paid" at the time of use, and this information will be used in calculating the revenue from the Managed Lane options.

In addition, the stakeholders are interested in the increase in transit ridership and associated revenue on the Red Line during events where mode shift is promoted. The Red Line LRT transit is the only viable option for carrying the growth in travel in the U.S. 75 Corridor. The additional ridership will be the difference in ridership between the pre-ICM run and the corresponding post-ICM run. This difference will be multiplied by the transit fare to derive the associated revenue.

Lastly, the stakeholders are interested in the parking utilization at Red Line stations. Several of the current lots are at (or over) capacity. However, there are three strategies that will affect parking: 1) comparative traveler information with available parking from the smart parking system; 2) station parking expansion with private lots; and 3) station parking expansion with valet parking. The stakeholders are interested in the impacts on parking for each of these different strategies. Similar to ridership, the additional parking utilization will be the difference in utilization between the pre-ICM run and the corresponding post-ICM run.

# Chapter 5. Model Calibration

Accurate calibration is a necessary step for proper simulation modeling. Before modeling ICM strategies, model calibration ensures that base scenarios represent reality, creating confidence in the scenario comparison.

## 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 and mode 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, regional mode-choice coefficient traffic flows, and travel times will be used for calibrating the simulation model for the analysis of the Pioneer Corridor. The U.S. 75 Corridor calibration strategy will be based on the following three-step strategy recommended in the FHWA Guidelines for Applying Traffic Microsimulation Modeling Software:[10]

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 Pioneer Corridor will have parallel arterial streets, making route choice calibration important. A second calibration process will be performed with the

[10] 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.

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.

In addition to the roadway variables, other variables such as the willingness of travelers to use transit, the value of time and operating cost could be adjusted during the calibration process to better reflect transit usage in the U.S. 75 Corridor study area.

## Validation Criteria

The validation criteria presented in Table 5-1 will be applied for the Pioneer Corridor simulation, subject to the budget and schedule constraints for the Pioneer Corridor AMS. Because of the transit viability of the U.S. 75 Corridor and DIRECT's ability to simulate different modes, the Dallas AMS team established a set of validation criteria for the transit component of the AMS stage. These criteria are shown in Table 5-2.

**Table 5-1. Model Validation Criteria for the Pioneer 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 vph | • For 85 percent of cases for links with peak-period volumes greater than 2,000 vph |
| • Sum of all link flows | • Within five percent of sum of all link counts |
| • Travel times within 15 percent | • > 85 percent of cases |
| • Visual Audits<br>Individual Link Speeds: Visually Acceptable Speed-Flow Relationship | • To analyst's satisfaction |
| • Visual Audits<br>Bottlenecks: Visually Acceptable Queuing | • To analyst's satisfaction |

**Table 5-2. Transit Validation Criteria for the Pioneer Corridor AMS**

| Validation Criteria and Measures | Validation Acceptance Targets |
|---|---|
| • Light-rail station passenger volumes within 20 percent of observed volumes | • For 85 percent of cases |
| • Light-rail park-and-ride lots: Individual lot usage | • Within 30 percent of actual |
| • Light-rail park-and-ride lots: Total lot usage | • Within 20 percent of actual |

## 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;
- OD surveys, if available, identifying travel patterns along the freeway and arterial components of the ICM Corridor;
- Queue observations along critical segments of the ICM Corridor freeway and arterial components;
- Bus and light-rail passenger counts; and
- Light-rail parking lot counts.

## 5.4 Model Sensitivity

After the mesoscopic model is 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 Dallas 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 the calibrated parameters, thus an update of the validated model. The Dallas AMS mined the available incident databases to compile information and data on an incident along the U.S. 75 Corridor, which could be used as the basis for the sensitivity analysis. The characteristics of the known incident are provided below:

- **Location –** Southbound U.S. 75, one-quarter-mile south of Belt Line Road;
- **Severity –** Major incident blocking two inside lanes;
- **Start time –** 6:50 a.m.;
- **Clearance time –** 7:40 a.m.; and
- **Time to clear lanes –** 50 minutes.

The detector data for the known incident day indicates that demand was at medium levels (6,900 to 7,500 vph). This is similar to the typical day demand used in the baseline conditions. Table 5-3 shows the criteria used for the known incident scenario based on U.S. DOT guidelines.

**Table 5-3. Validation and Calibration Criteria for Known Incident**

| Validation Criteria and Measures | Validation Acceptance Targets |
|---|---|
| • Incident-related congestion duration | • Within 25 percent of observed duration |
| • Extent of queue propagation | • Within 20 percent of observed queues |
| • Traffic flow diversion | • Reasonable changes in link volumes where expected |

# Chapter 6. Documentation

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

- **Section 1.0** will outline the principles guiding the development and application of ICM AMS;
- **Section 2.0** will present the AMS methodology, and will provide a summary of the Pioneer Corridor site;
- **Section 3.0** 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 4.0** 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 illustrates the proposed schedule. The Southern Methodist University (SMU) team will implement the HOT lane algorithms, validate the DIRECT model, and run the future scenarios. TTI will have responsibility for data. CS will assist SMU 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**

| No. | Stage 2 AMS Milestone | Completion Goal |
|---|---|---|
| 1 | Baseline Calibration/Validation | November 2009 |
| 2 | Baseline Model Sensitivity | November 2009 |
| 3 | Performance Measures Definition | March 31, 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. Summary of Pre- and Post-ICM Strategies

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

**Table A-1. Dallas ICM – Table Outlining Assumptions of Outcomes and Effects**

| | | Model Assumptions/Inputs | |
|---|---|---|---|
| Strategy | Expected Outcome/Effect | Pre-ICM (2011) | Post-ICM (2011) |
| *Traveler Information* | | | |
| Comparative, multimodal travel time information (pretrip and en-route) | Pretrip and en-route traveler information will be disseminated, including incidents, freeway travel time, arterial travel time, Red Line travel time to major destinations, and park-and-ride lot availability via radio, TV, GPS, DMS, and the Internet. The strategy will result in a more reliable information dissemination and potential route and mode diversions. | • Pretrip awareness: 10 percent;<br>• En-route awareness: 50 percent;<br>• Pretrip use: 10 percent; and<br>• En-route use: 20 percent. | • Pretrip awareness: 20 percent;<br>• En-route awareness: 60 percent;<br>• Pretrip use: 20 percent; and<br>• En-route use: 30 percent. |
| *Traffic Management* | | | |
| Incident signal retiming plans for frontage roads | Cities of Dallas, Plano, and Richardson will implement signal timing plans to increase green time on southbound through movements at frontage road diamond interchanges. | • No coordination. | • Modify frontage road DIRECT signal timings to achieve 15 percent increase in throughput. |
| Incident signal retiming plans for arterials and frontage roads | Cities of Dallas, Plano, and Richardson will implement coordinated plan on Greenville Ave in north-south direction in addition to frontage road retiming as described above. | • No coordination. | • Modify Greenville DIRECT signal timings to achieve 15 percent increase in throughput. |

**Table A-1. Dallas ICM – Table Outlining Assumptions of Outcomes and Effects (continued)**

| Strategy | Expected Outcome/Effect | Model Assumptions/Inputs Pre-ICM (2011) | Model Assumptions/Inputs Post-ICM (2011) |
|---|---|---|---|
| *HOT/HOV Lanes* | | | |
| HOT lane (congesting pricing) | HOV 2+ continue to travel HOV lane for free. SOVs access the HOV lane and pay a full toll set by congestion pricing. Increase peak hour freeway vehicle throughput by 20 percent and person throughput by 25 percent. | • HOV lane in 2011. | • The managed lanes in the Dallas area will most likely use open road tolling with the region's current tolling technology. In 2007, 86 percent of NTA's toll road users had transponders that allow for open-road tolling. By 2011, the percentage of vehicles with transponders is expected to increase to as much as 90 to 95 percent as the region constructs more toll roads and managed lanes. For modeling purposes, DIRECT it will be assumed that all vehicles on the freeway are equipped with a transponder and available to use the managed lane if they meet the occupancy and generalized cost threshold.<br>• Use density threshold to adjust price (if needed) every five minutes. |
| Express toll lane (congestion pricing) | HOV 2+ use the HOV lane for one-half price toll. SOVs access the HOV lane and pay a full toll set by congestion pricing. Increase peak hour freeway vehicle throughput by 20 percent and person throughput by 20 percent. | • HOV lane in 2011. | • Same assumptions as the HOT lane. |

**Table A-1. Dallas ICM – Table Outlining Assumptions of Outcomes and Effects (continued)**

| Strategy | Expected Outcome/Effect | Model Assumptions/Inputs: Pre-ICM (2011) | Model Assumptions/Inputs: Post-ICM (2011) |
|---|---|---|---|
| *Transit Management* | | | |
| LRT smart parking system | Parking systems at LRT stations allow for real-time counts of parking availability for all eight lots along DART Red Line. Throughout day, the parking availability information will be disseminated by radio, TV, DMS, and the Internet. Availability of Red Line station parking is available pretrip and en-route. During major incident scenarios, Red Line ridership and station parking north of incident increase cumulatively by 10 percent. | • Station parking availability is not known to travelers. Red Line Parker and PGBT stations reach capacity each day. | • In DIRECT, the parking lot capacity will be kept at five percent below the actual lot capacity in the pre-ICM scenario. When the lot reaches this threshold, paths with park-and-ride will not be allowed. |
| Red Line Capacity Increase | DART decreases headways to Red Line to increase capacity on days with higher expected demand due to mode shifts during major traffic accidents. Red Line ridership increases cumulatively by 10 percent. | • Red Line operating below capacity. | • Decrease Red Line headways from 10 minutes to 7.5 minutes. |
| Station parking expanded with private parking | DART adds shuttle bus service from private parking lots to Red Line PGBT station to handle increase in transit demand. Red Line ridership increases cumulatively by 10 percent. | • 1,193 spaces at PGBT station. | • In DIRECT, the PGBT nominal lot capacity (1,193 vehicles) will be increased by 250 spaces to reflect the available private parking. As soon as the PGBT nominal lot capacity is reached, each additional traveler utilizing the overflow capacity will be assessed with a time penalty to represent the time to "go to" the nearby private lot and for the shuttle service back to the PGBT station. |
| Station parking expanded with valet parking | DART runs valet parking service from the Red Line PGBT station. Transit riders can drop car off at station and not search for parking spot. Valet will retrieve car upon transit rider's return to station. Increased parking at the Red Line PGBT station Red Line ridership increases cumulatively by 10 percent. | • 1,193 spaces at PGBT station. | • Similar to the private parking, but no penalty will be assessed. |

# APPENDIX B. U.S. DOT Guidance on Performance Measures

Appendix B 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 $\tau'$ using mode $m$.

We record travel time from a single run of the simulation under operational conditions $k$ for this unit of observation as $t_i^k = t_{o,d,\tau',m}^k$.[11] *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 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 $\tau$ represent this interval (e.g., an interval between 6:30 a.m. and 6:45 a.m.) and $\mathbf{I}_{o,d,\tau,m}^k$ the set of $n_{o,d,\tau,m}^k$ trips from $o$ to $d$ starting in interval $\tau$ under operational condition $k$ using mode $m$. Note that $\mathbf{I}_{o,d,\tau,m}^k$ is a collection of trips and $n_{o,d,\tau,m}^k$ the scalar value indicating the number of trips contained in $\mathbf{I}_{o,d,\tau,m}^k$.

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, $\bigcup_m \boldsymbol{I}_{o,d,\tau,m}^k = \boldsymbol{I}_{o,d,\tau}^k$ and $\sum_m n_{o,d,\tau,m}^k = n_{o,d,\tau}^k$.

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

$$T_{o,d,\tau,m}^k = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^k} t_i^k}{n_{o,d,\tau,m}^k}$$

(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 $\tau$ over all conditions $k \in K$:

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

(Equation 2)

[11] 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.

The average number of trips by mode from $o$ to $d$ starting in interval $\tau$ 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 $\tau$ 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 $\tau$ 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 $\tau$ 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 $o, d, \tau$:

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

(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 $o, d, \tau$ 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 $\tau$ (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 $o,d,\tau,m$:

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

(Equation 7)

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

$$D_{o,d,\tau} = \frac{\sum_m D_{o,d,\tau,m}}{n_{o,d,\tau}}$$

(Equation 8)

Systemwide average trip delay:

$$D = \frac{\sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}}$$

(Equation 9)

Aggregating this average delay over all trips produces total system delay:

$$\hat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}$$

(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 $\tau$ 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 95$^{th}$ percentile travel time is selected. Note that this percentile is calculated considering travel times for similar trips (i.e., $o,d,\tau$) 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 $o,d,\tau$:

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

(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 $o,d,\tau$. 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 $\tau$ 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 $o,d,\tau$ 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 $\tau' \in \tau$:

$$V_{o,d,\tau}^{k} = \frac{\sum_{\tau' \in \tau} \left(t_{o,d,\tau'}^{k} - T_{o,d,\tau}^{k}\right)^2}{n_{o,d,\tau}^{k} - 1}$$

(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 $o,d,\tau$ 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.[12]

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

(Equation 14a)

The average variance among all $o,d,\tau$ 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 $\tau'$ we obtain from the simulation the travel time $t_{o,d,\tau'}^{k}$ and a distance traveled $s_{o,d,\tau'}^{k}$. In some cases, trip-level outputs from the simulation are only available at a vehicle level, so some trips

[12] 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.

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 $\tau$.

$$X^{k}_{o,d,\tau} = \frac{\sum_{i \in \mathbf{I}^{k}_{o,d,\tau}} s^{k}_{i} x^{k}_{i}}{n^{k}_{o,d,\tau}} \quad \text{(Equation 15)}$$

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 $\tau$ over all operational conditions $k \in K$:

$$X_{o,d,\tau} = \sum_{k \in K} X^{k}_{o,d,\tau} p_{k} \quad \text{(Equation 16)}$$

Equation 17 defines the aggregate PMT across all $o,d,\tau$:

$$X = \sum_{\forall o,d,\tau} X_{o,d,\tau} n_{o,d,\tau} \quad \text{(Equation 17)}$$

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 $\dot{\mathbf{I}}^{k}_{o,d,\tau}$ be the set of trips from $o$ to $d$ starting in interval $\tau$ 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 $o,d,\tau$ level.

$$Y^{k}_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^{k}_{o,d,\tau}} x^{k}_{i}}{n^{k}_{o,d,\tau}} \quad \text{(Equation 18)}$$

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

$$Y_{o,d,\tau} = \sum_{k \in K} Y_{o,d,\tau}^{k} \, p_k \qquad \text{(Equation 19)}$$

Equation 20 defines the aggregate PTD across all $o, d, \tau$:

$$Y = \sum_{\forall o,d,\tau} Y_{o,d,\tau} \, n_{o,d,\tau} \qquad \text{(Equation 20)}$$

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

$$Z_{o,d,\tau}^{k} = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^{k}} s_i^k x_i^k}{n_{o,d,\tau}^{k}} \qquad \text{(Equation 21)}$$

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

$$Z_{o,d,\tau} = \sum_{k \in K} Z_{o,d,\tau}^{k} \, p_k \qquad \text{(Equation 22)}$$

Equation 23 defines the aggregate PMD across all $o, d, \tau$:

$$Z = \sum_{\forall o,d,\tau} Z_{o,d,\tau} \, n_{o,d,\tau} \qquad \text{(Equation 23)}$$

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 origin $o$, destination $d$ starting a trip in time interval $\tau$ 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 $\tau$ 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 $\overleftarrow{t}_i^k$ 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 are then made to characterize corridor performance under each case.

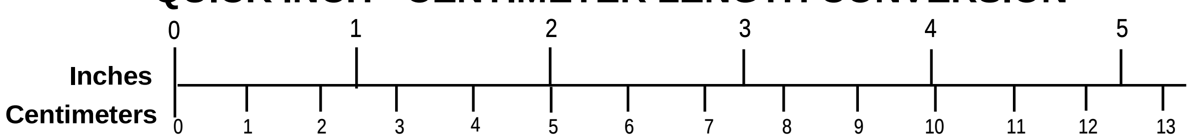
## Comparing Observed and Simulated Performance Measures

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.

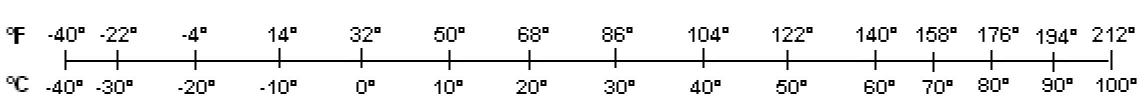
# APPENDIX C. Metric/English Conversion Factors

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