Guide for Highway Capacity and Operations Analysis of Active Transportation and Demand Management Strategies

Analysis of Operational Strategies Under Varying Demand and Capacity Conditions

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Foreword

ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real-time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency.

Under an ATDM approach the transportation system is continuously monitored. Using archived data and/or predictive methods, actions are performed in real-time to achieve or maintain system performance. Active management of transportation and demand can include multiple approaches spanning demand management, traffic management, parking management, and efficient utilization of other transportation modes and assets.

This Guide provides a conceptual analysis framework, recommended measures of effectiveness, and an initial recommended methodology for evaluating the impacts of ATDM strategies on highway and street system demand, capacity, and performance. Although the Guide describes various ATDM "strategies" and "measures" it should be noted that most any system management or operations strategy that is applied in a dynamic manner can be considered active management.

The Methodology for Capacity and Operations Analysis of ATDM presented here should be viewed as an initial, foundational methodology primarily focused on traffic management applications. In some cases, the operations strategies presented here may be relatively static (e.g., fixed ramp metering rates or toll rate schedules). However, it is necessary to present these as the starting points in order to analyze the benefits of applying dynamic treatments. It is also recognized that there are several gaps in our knowledge of the effects of ATDM strategies, which can only be filled as more experience is gained with ATDM applications in the United States. It is hoped that the conceptual analysis framework laid out in this Guide will provide the framework for the future research that will fill those gaps.

The Guide presents practitioners with methods to represent the varied demand and capacity conditions that facilities may be expected to operate under and methods to apply a limited but broad set of transportation management actions to respond to those conditions Thus, the methodology represents, in a macroscopic sense, the effects of ATDM at a level suitable for planning and investment decision-making but not real-time operations. This Guide is designed to be used in conjunction with the Transportation Research Board's Highway Capacity Manual (HCM) for the planning, programming, and design of ATDM measures.

Although the Guide is intended to support ATDM analysis and provide content for Chapter 35 (Active Traffic Management) of the HCM, several aspects of the methodology, such as accounting demand variability, incidents, and weather scenarios, can also be applied to analyzing capacity and other non-operations type strategies.

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16. Abstract

This Guide provides a conceptual analysis framework, recommended measures of effectiveness, and an initial recommended methodology for evaluating the impacts of ATDM strategies on highway and street system demand, capacity, and performance. The Guide presents practitioners with methods to analyze the varying demand and capacity conditions that facilities operate under and methods to apply a limited but broad set of transportation management actions to respond to those conditions Thus, the methodology represents, in a macroscopic sense, the effects of ATDM at a level suitable for planning and investment decision-making but not real-time operations. This Guide is designed to be used in conjunction with the Transportation Research Board's Highway Capacity Manual (HCM) for the planning, programming, and design of ATDM measures.

Although the Guide is intended to support ATDM analysis and provide content for Chapter 35 (Active Traffic Management) of the HCM, several aspects of the methodology, such as accounting for demand variability, incidents, and weather scenarios, can also be applied to analyzing capacity and other non-operations type strategies.

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1 Introduction

ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real-time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency. Under an ATDM approach, the transportation system is continuously monitored. Using archived data and/or predictive methods, actions are performed in real-time to achieve or maintain system performance. ATDM is a transportation-specific application of Active Management. Active Management is the fundamental concept of taking a dynamic approach to a performance-based process which is routinely used in many other industry sectors such electrical utilities, telecommunications, information technology network management. Figure 1 depicts the four key steps in the active management cycle.

Figure 1: The Active Management Cycle

Source: FHWA.

This Guide focuses on the analysis of active traffic management, and to a lesser degree, active demand management approaches. Additional information and resources on ATDM and the FHWA ATDM program activities can be found at http://www.ops.fhwa.dot.gov/atdm/.

1.1 Purpose

This Guide provides HCM-related methodologies and measures of effectiveness for evaluating the impacts of ATDM strategies on highway and street system demand, capacity, and performance. The Guide is designed to assist engineers and planners in evaluating the traffic operations effects of various ATDM strategies on a specific facility and to determine which combination of strategies best achieves a desired operational goal for a facility. As such, the Guide will be valuable for the planning, prioritization, and programming of ATDM investments.

Organization

This Guide is organized as follows:

- *Chapter 1: Introduction:* describes the scope, purpose, limitations, and organization of the Guide.
- *Chapter 2: Measures of Effectiveness* – presents recommended measures that build on traditional HCM measures for assessing the effectiveness of ATDM measures.
- *Chapter 3: ATDM Strategies Toolbox* – provides an overview of active transportation and demand management measures.

- *Chapter 4: Overview of ATDM Analysis Methodology* – provides an overview of the ATDM Analysis methodology.
- *Chapter 5: Methodology* – presents the methodology in step-by-step detail.
- *Chapter 6: Example Application* – provides a worked example application of the methodology.
- *Chapter 7: Use of Alternative Tools* – provides brief guidance on the use of other traffic operations analysis tools besides the HCM to evaluate ATDM investments.

The Appendices provide additional background on the development of demand, free-flow speed, and capacity adjustment factors for weather, incidents, and work zones.

Scope and Limitations

The methodology described here is designed to be applied to any traffic control, toll, or capacity improvement that affects the demand, capacity, speed, and reliability of a highway facility. The methodology should be viewed as an initial, foundational methodology primarily focused on traffic management applications. In some cases, the operations strategies presented here may be relatively static (e.g., fixed ramp metering rates or toll rate schedules). However, it is necessary to present these as the starting points in order to analyze the benefits of applying dynamic treatments. It is also recognized that there are several gaps in our knowledge of the effects of ATDM strategies, which can only be filled as more experience is gained with ATDM applications in the United States. It is hoped that the conceptual analysis framework laid out in this Guide will provide the framework for the future research that will fill those gaps.

The analyst can use any traffic operations analysis tool sensitive to ATDM measures (e.g., Highway Capacity Manual, microscopic simulation, mesoscopic simulation) to evaluate ATDM with the methodology described here. For the purposes of this Guide, which is based on HCM-based procedures, the methodology is demonstrated for the facility level only, since the HCM does not currently include system-level analysis. Specifically, the procedure given in Chapter 10 of the HCM ("Freeway Facilities") is used as the underlying analytical procedure. Layered on top of the Chapter 10 procedure is a "scenario generator" that develops combinations of traffic, disruption, and weather conditions to be analyzed. This requires that multiple runs be made and their outputs combined to develop a complete picture of how a facility operates over time. The scenario generator is a simpler version of the procedure recently developed in Strategic Highway Research Program 2 (SHRP 2) Project L08 ("Incorporating Travel Time Reliability into the HCM"). The SHRP 2-L08 procedure also uses HCM Chapter 10 procedures as the underlying analytical engine but develops a more complete enumeration of the possible conditions affecting a facility's performance in terms of the variability in traffic demand, incident conditions, weather conditions, and work zones. The limitations of the ATDM Analysis are determined by the limitations of the traffic operations analysis tool used to conduct the Analysis. Where Highway Capacity Manual methods are used for the traffic operations analysis, the analysis is subject to the same limitations as the selected HCM method.

Like all traffic operations analyses, the estimation of delay and other performance measures when evaluating ATDM strategies hinges on the ability of the analyst to identify a large enough study area and study time period to fully cover the geographic and temporal extent of congestion affected by ATDM. Resource limitations will often limit the ability to identify a sufficiently large study area and a sufficiently long study time period for analysis. The analyst must then develop manual corrections to the forecasted performance.

The quality of the analysis depends on the quality of historical data available for estimating how demands and capacities will vary on the facility before and after implementation of ATDM. Six months of historical data on demands, and a year's worth of historical data on incidents and weather are desirable for evaluating ATDM using the methodology described here. However, reasonable estimates of ATDM performance can be approximated from a 10-day sample of facility demand, as long as the sample adequately represents 6 to 12 months of actual conditions; this can be done by expanding the sample using factors developed on similar facilities or by using default values.

For many ATDM strategies there is relatively little available U.S. experience for assessing the impacts of the strategies on demand, capacity, and speeds. Where data on the effects is lacking for a specific strategy, this Guide provides a "reasonable" estimate of the likely effect that can be used until research or experience provides better information. In such cases, the analyst should use great care in interpreting the results based on these estimated effects and recognize the uncertainty in the results produced using these estimates.

2 The ATDM Strategy Tool Box

Active management of transportation and demand can include multiple approaches spanning demand management, traffic management, parking management, and efficient utilization of other transportation modes and assets. Some example approaches are included in Table 1. It should be noted that the strategies covered by this Guide deal primarily with Active Traffic Management strategies. Active Parking Management strategies are not covered at all, and only static demand management strategies are covered.

Table 1: Example ATDM Approaches Strategies

Active Demand Management	Active Traffic Management	Active Parking Management
Dynamic Ridesharing	Dynamic Lane Use/Shoulder Control	Dynamically Priced Parking
On-Demand Transit	Dynamic Speed Limits	Dynamic Parking Reservation
Dynamic Pricing	Queue Warning	Dynamic Way-Finding
Predictive Traveler Information	Adaptive Ramp Metering	Dynamic Parking Capacity

2.1 Active Traffic Management

Active traffic management (ATM) is the ability to dynamically manage recurring and nonrecurring congestion based on prevailing and predicted traffic conditions. Focusing on trip reliability, it maximizes the effectiveness and efficiency of the facility. ATM approaches seek to increase throughput and safety through the use of integrated systems with advanced technology, including the automation of dynamic deployment to optimize performance. In addition to the approaches listed in the table above, other ATM strategies and their descriptions are:

- **Adaptive Ramp Metering**: This strategy consists of deploying traffic signal(s) on ramps to dynamically control the rate vehicles enter a freeway facility. This has the effect of smoothing the flow of traffic onto the mainline, allowing efficient use of existing freeway capacity. Adaptive ramp metering utilizes traffic responsive or adaptive algorithms (as opposed to pre-timed or fixed time rates) that can optimize either local or systemwide conditions. Adaptive ramp metering can also utilize advanced metering technologies such as dynamic bottleneck identification, automated incident detection, and integration with adjacent arterial traffic signal operations. In an ATDM approach, real-time and anticipated traffic volumes on the freeway facility are used to control the rate of vehicles entering the freeway facility. Based on the conditions, the ramp meter rates are adjusted dynamically.

Figure 2: Freeway Ramp Metering, SR 94, Lemon Grove, California

Source: FHWA, Ramp Management and Control, A Primer (1).

- **Adaptive Traffic Signal Control**: This strategy continuously monitors arterial traffic conditions and the queuing at intersections and dynamically adjusts the signal timing to optimize one or more operational objectives (such as to minimize overall delays). Adaptive Traffic Signal Control approaches typically monitor traffic flows upstream of signalized locations or segments with traffic signals, anticipating volumes and flow rates in advance of reaching the first signal, then continuously adjusting timing parameters (e.g., phase length, offset, cycle length) during each cycle to optimize operational objectives.
- **Dynamic Junction Control**: This strategy consists of dynamically allocating lane access on mainline and ramp lanes in interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day. For off-ramp locations, this may consist of assigning lanes dynamically either for through movements, shared through-exit movements, or exit-only. For on-ramp locations, this may involve a dynamic lane reduction on the mainline upstream of a high-volume entrance ramp, or might involve extended use of a shoulder lane as an acceleration lane for a two-lane entrance ramp which culminates in a lane drop. In an ATDM approach, the volumes on the mainline lanes and ramps are continuously monitored and lane access will be dynamically changed based on the real-time and anticipated conditions.
- **Dynamic Lane Reversal or Contraflow Lane Reversal**: This strategy consists of the reversal of lanes in order to dynamically increase the capacity of congested roads, thereby allowing capacity to better match traffic demand throughout the day. In an ATDM approach, based on the real-time traffic conditions, the lane directionality is updated quickly and automatically in response to or in advance of anticipated traffic conditions.
- **Dynamic Lane Use Control**: This strategy involves dynamically closing or opening of individual traffic lanes as warranted and providing advance warning of the closure(s) (typically through dynamic lane control signs), in order to safely merge traffic into adjoining lanes. In an ATDM approach, as the network is continuously monitored, real-time incident and congestion data is used to control the lane use ahead of the lane closure(s) and dynamically manage the location to reduce rear-end and other secondary crashes.
- **Dynamic Merge Control**: This strategy (also known as dynamic late merge or dynamic early merge) consists of dynamically managing the entry of vehicles into merge areas with a series of advisory messages (e.g., displayed on a dynamic message sign (DMS) or lane control sign). As motorists approach the merge point, they are prepared for an upcoming merge and are directed to use a consistent merging behavior. Applied conditionally during congested (or near congested) conditions, dynamic merge control can help create or maintain safe merging gaps and reduce shockwaves upstream of merge points. In an ATDM approach,

conditions on the mainline lanes and ramps approaching merge areas are continuously monitored and the dynamic merge system will be activated dynamically based on real-time and anticipated congestion conditions.

- **Dynamic Shoulder Lanes**: This strategy enables the use of the shoulder as a travel lane(s), known as Hard Shoulder Running (HSR) or temporary shoulder use, based on congestion levels during peak periods and in response to incidents or other conditions during nonpeak periods. In contrast to a static time-of-day schedule for using a shoulder lane, an ATDM approach continuously monitors conditions and uses real-time and anticipated congestion levels to determine the need for using a shoulder lane as a regular or special purpose travel lane (e.g., transit only).
- **Dynamic Speed Limits**: This strategy adjusts speed limits based on real-time traffic, roadway, and/or weather conditions. Dynamic speed limits can either be enforceable (regulatory) speed limits or recommended speed advisories, and they can be applied to an entire roadway segment or individual lanes. In an ATDM approach, real-time and anticipated traffic conditions are used to adjust the speed limits dynamically to meet an agency's goals/objectives for safety, mobility, or environmental impacts.
- **Queue Warning:** This strategy involves real-time displays of warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists that queues or significant slowdowns are ahead, thus reducing rear-end crashes and improving safety. In an ATDM approach, as the traffic conditions are monitored continuously, the warning messages are dynamic based on the location and severity of the queues and slowdowns.
- **Transit Signal Priority**: This strategy manages traffic signals by using sensors or probe vehicle technology to detect when a bus nears a signal controlled intersection, turning the traffic signals to green sooner or extending the green phase, thereby allowing the bus to pass through more quickly. In an ATDM approach, current and predicted traffic congestion, multi-agency bus schedule adherence information, and number of passengers affected, may all be considered to determine where and when transit signal priority may be applied.

2.2 Active Demand Management

Active Demand Management (ADM) uses information and technology to dynamically manage demand, which could include redistributing travel to less congested times of day or routes, or reducing overall vehicle trips by influencing a mode choice. ADM seeks to influence more fluid, daily travel choices to support more traditional, regular mode choice changes. ADM is very supportive of other active measures because it redistributes or reduces overall traffic levels during congested conditions, thus becoming an integral part of an overall management philosophy to actively manage a facility or system. Example of ADM strategies include:

- **Dynamic Fare Reduction:** This strategy involves reducing the fare for use of the transit system in a particular corridor as congestion or delay on that corridor increases. This encourages selection of the transit mode to reduce traffic volumes entering the corridor. Fare changes are communicated in real-time to the traveling public, through general dissemination channels such as a transit web site, as well as personalized messages to subscribers. In an ATDM approach, real-time and predicted highway congestion levels and/or the utilization levels of the transit system can be used to adjust transit fare in real-time to encourage mode shift necessary to meet agencies goals and objectives.
- **Dynamic High-Occupancy Vehicle (HOV)/Managed Lanes:** This strategy involves dynamically changing the qualifications for driving in a high-occupancy vehicle (HOV) lane(s). HOV lanes (also known as carpool lanes or diamond lanes) are restricted traffic lanes reserved at peak travel times or longer for exclusive use of vehicles with a driver and one or more passengers, including carpools, vanpools and transit buses. The normal minimum occupancy level is 2 or 3 occupants. Many agencies exempt other vehicles, including motorcycles, charter buses, emergency and law enforcement vehicles, low-emission vehicles, and/or single-occupancy vehicles paying a toll. In an ATDM approach, the HOV lane qualifications are dynamically changed based on real-time or anticipated conditions on both the HOV and general purpose lanes. Factors that can potentially be dynamically adjusted include the number of occupants (e.g., from 2 to 3 occupants), the hours of operation, and the exemptions (e.g., change from typical HOV operation to buses only).

Alternatively, the HOV restrictions could be dynamically removed allowing general use of the previously managed lane.

- **Dynamic Pricing:** This strategy utilizes tolls that dynamically change in response to changing congestion levels, as opposed to variable pricing that follows a fixed schedule. In an ATDM approach, real-time and anticipated traffic conditions can be used to adjust the toll rates to achieve agency goals and objectives.

Figure 3: Minnesota Dynamic Pricing for HOT Lanes

Source: FHWA: Technologies That Complement Congestion Pricing (2) (Courtesy of MnDOT).

- **Dynamic Ridesharing:** This strategy involves travelers using advanced technologies, such as smart phones and social networks, to arrange a short-notice, one-time, shared ride. This facilitates real-time and dynamic carpooling to reduce the number of auto trips/vehicles trying to use already congested roadways.
- **Dynamic Routing:** This strategy uses variable destination messaging to disseminate information to make better use of roadway capacity by directing motorists to less congested facilities. These messages could be posted on dynamic message signs in advance of major routing decisions. In an ATDM approach, real-time and anticipated conditions can be used to provide route guidance and distribute the traffic spatially to improve overall system performance.
- **Dynamic Transit Capacity Assignment:** This strategy involves reorganizing schedules and adjusting assignments of assets (e.g., buses) based on real-time demand and patterns, to cover the most overcrowded sections of network. In an ATDM approach, real-time and predicted travel conditions can be used to determine the changes needed to the planned transit operations, thereby potentially reducing traffic demand and subsequent delays on roadway facilities.
- **On-Demand Transit:** This strategy involves travelers making real-time trip requests for services with flexible routes and schedules. This allows users to request a specific transit trip based on their individual trip origin/destination and desired departure or arrival time.
- **Predictive Traveler Information:** This strategy involves using a combination of real-time and historical transportation data to predict upcoming travel conditions and convey that information to travelers pre-trip

and en-route (such as in advance of strategic route choice locations) in an effort to influence travel behavior. In an ATDM approach, predictive traveler information is incorporated into a variety of traveler information mechanisms (e.g., multimodal trip planning systems, 511 systems, dynamic message signs) to allow travelers to make better informed choices.

- **Transfer Connection Protection:** This strategy involves improving the reliability of transfers from a high-frequency transit service (e.g., a train) to a low-frequency transit service (e.g., a bus). For example, the train is running late, so the bus is held back so train passengers can make their connection with the bus; or providing additional bus services at a later time to match the late arrival time of the train. This ensures that the connections are not missed.

2.3 Active Parking Management

Active Parking Management is the dynamic management of parking facilities in a region to optimize performance and utilization of those facilities while influencing travel behavior at various stages along the trip-making process. Dynamically managing parking can affect travel demand by influencing trip timing choices, mode choice, as well as parking facility choice at the end of the trip. This ATDM approach can also have a positive impact on localized traffic flow by providing real-time parking information to users and ensuring the availability of spaces to reduce circling around parking facilities. Examples include:

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

- **Dynamic Parking Reservation:** This strategy provides travelers with the ability to utilize technology to reserve a parking space at a destination facility on demand to ensure availability. In an ATDM approach, the parking availability is continuously monitored and system users can reserve the parking space ahead of arriving at the parking location.

- **Dynamic Wayfinding:** This is the practice of providing real-time parking-related information to travelers associated with space availability and location so as to optimize the use of parking facilities and minimize the time spent searching for available parking. In an ATDM approach, the parking availability is continuously monitored and routing information to the parking space is provided to the user.

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

3 Measuring the Success of ATDM Implementation

3.1 Introduction

The overarching goal of active transportation and demand management (ATDM) is to increase the productivity and efficiency of the transportation system. ATDM achieves this goal by better tailoring systems operations and control to match fluctuating demand, weather and incident conditions, and by better informing travelers of these conditions so that they make more efficient use of the available system capacity.

Conventional analysis methodologies of roadway capacity improvements are designed to produce a single set of performance results (measures of effectiveness or MOEs) for a given set of input demands and computed capacities for a facility.[1] In addition, conventional methodologies are often specifically oriented to "ideal" or "near-ideal" conditions, when weather, incidents, and other factors do not adversely affect capacity. Conventional Highway Capacity Manual (HCM) and simulation model methodologies can be adapted to account for adverse effects on capacity, but their default condition is to exclude these effects.

3.2 Criteria for ATDM Performance Measurement

ATDM performance measures are designed to improve the performance of the facility over a range of real-world demand and capacity conditions, not just for a single forecasted condition. The conventional performance measures and methodologies overlook the majority of the benefits of the dynamic control of the transportation system provided by ATDM. Thus, ATDM performance measures must be able to measure not only improvements in average performance; they must also be able to measure improvements in the variability or reliability of that performance.

In addition, because ATDM is designed to be applied at a facility or system level, the performance measures for ATDM must be at the complete facility or system level. Consequently performance measures that are typically used for system level of analysis are recommended for evaluating ATDM strategies.

This chapter focuses on numerical measures of performance, however; much can be learned by examining graphical measures of performance such as the speed profile for the facility over the course of time and over the length of the facility. This can be particularly useful in diagnosing the causes and extent of unreliable performance.

3.3 Performance Measures (Measures of Effectiveness) for ATDM Analysis

A suite of performance measures, also referred to as "measures of effectiveness" in this Guide, are recommended to characterize the impacts of ATDM strategies on travel and congestion.

The performance measures are reported for each scenario, then weighted by their appropriate probability and summed across scenarios to provide overall performance results. The performance measures recommended are:

The **VMT-Demand** is the total number of vehicle-trips attempting to use the facility during the time period of interest. It is calculated as the sum of the products of the input origin-destination (OD) table vehicle-trips and

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[1] "Measures of effectiveness" and "performance measures" are terms that can be used interchangeably.

the shortest path distance between each origin and destination. For example, a certain number of vehicles entering a freeway at on-ramp number one will want to exit at off-ramp number 5. The number of those vehicles is the OD demand between those two ramps. Multiplying the OD Demand between the two ramps by the distance between them gives the VMT-Demand for that pair of ramps. Repeating this computation and summing the results for all possible mainline and ramp pairs, gives the VMT-Demand for the freeway facility. Although, not traditionally a performance measure for highway improvement projects, demand is a measure of the success of ATDM at managing the demand for the facility. Thus, for ATDM, demand is a performance measure of demand management actions of ATDM.

The **VMT-Served** is the sum of the products of the total link volumes for the time period of interest and the link lengths. VMT served is a measure of the productivity of facility, the improvement of which is one of the key objectives of ATDM.

> ***Diagnostic Tip:*** *VMT-Demand and VMT-Served are ATDM performance measures in their own right. However the difference between the two can be useful for determining if the analyst has selected the appropriate study area and study time for evaluation. For each scenario VMT-Demand should be equal or nearly equal to the VMT-Served for each scenario. This indicates that the analyst successfully selected a study area and peak period that was able to clear all demand for each of the scenarios. If VMT-Demand is greater than VMT-Served for any individual scenario, then the analyst may need to expand the study period or make a manual adjustment to the reported results to account for the unserved demand.*

The **Vehicle-Hours Traveled** (VHT) is the sum of the products of the total link volumes and the average link travel times. Delays to vehicles prevented from entering the facility each 15-minute time slice[2] either by controls (such as ramp metering) termed vehicle hours of entry delay or by congestion (VHED), are added to and included in the reported VHT total.

The **Vehicle-Hours Delay** (VHD) is the difference between the VHT (including vehicle-entry delay) and the theoretical VHT if all links could be traversed at the free-flow speed with no entry delays. VHD is summed over all time slices within the scenario. VHD is useful in determining the economic costs and benefits of ATDM measures. VHD highlights the delay component of system VHT.

Vehicle-hours of entry delay (VHED) for a scenario is the number of vehicles prevented from entering the system each time slice, multiplied by the duration of the time slice and summed over all time slices. VHED should be included in the computed VHD and VHT for each scenario.

$$VHD = VHT - VHT(FF)$$

Equation 1

Where:

VHD = Vehicle-Hours Delay

VHT = Vehicle-hours traveled including vehicle entry delay.

VHT(FF) = Vehicle-hours traveled recomputed with segment free-flow speeds. Vehicle-entry delay is set to zero.

If multiple paths available to destination, then the VHT is computed for shortest travel time path at free-flow speeds.

Agencies may elect to exclude from the delay the difference between the free-flow speed and the speed at capacity. The vehicle-hours of delay then become the time spent in queuing.

[2] The methodology analyzes conditions in 15-minute time intervals, in accordance with HCM concepts.

Average System Speed (measured in miles per hour) is a measure of the efficiency of the highway system. It is computed by summing up the VMT-Served for each scenario and then dividing by the sum of the scenario VHTs (including any vehicle entry delay). One of the key objectives of ATDM is to maximize the productivity of the system, serving the greatest amount of VMT at the least cost to travelers in terms of VHT. Thus changes in the average system speed are a good overall indicator of the relative success of the ATDM strategy at achieving its objective of improving efficiency.

The **Vehicle-Hours Delay/Vehicle-Trip** (VHD/VT) is the vehicle-hours delay summed over all of the scenarios divided by the sum of the number of vehicle trips in the OD tables for all of the scenarios. This gives the average delay per vehicle, which is useful for conveying the results in a manner that can be related to personal experience.

The **80th Percentile Travel Time Index** is a measure of the reliability of travel times on the facility. While historically various travel time percentiles have been used to describe travel time reliability, it is recommended that the 80 percentile highest travel time be used for the predicted travel time. The 80th percentile travel time has a more stable relationship to the mean travel time than the 90th, 95th, or 99th percentiles, which is useful in predicting changes in reliability based on changes in the mean travel time. The formula for computing the 80th Percentile Travel Time Index is given below.

$$80\%TTI = \frac{\left[VHT / VMT\right]_{80th\%}}{\left[VHT / VMT\right]_{Free-Flow}}$$

Equation 2

Where:

80%TTI = 80th Percentile Planning Travel Time Index

VHT(80%) = 80th percentile highest vehicle-hours traveled among the scenarios evaluated

VMT(80%) = Vehicle-miles traveled for scenario with 80th percentile highest vehicle-hours traveled among the scenarios evaluated

VHT(FF) = Vehicle-hours computed with segment free-flow speeds.

VMT(FF) = Vehicle-miles traveled with segment free-flow speeds.

The **Planning Time Index** (PTI) is a measure of the reliability of travel times on the facility. It is the ratio of the estimated travel time to the free-flow travel time. It is computed using Equation 2 with the 95th percentiles substituted for the 80th percentiles. For example, a PTI of 1.50 means that the traveler must allow 50% extra time over free-flow travel time to get to their destination on-time. Put another way, a commute will arrive late one day per month (1 of out 20 weekdays) if they plan their trip at the PTI.

VMT-Demand, VMT-Served, Vehicle-Hours Traveled, and Vehicle-Hours Delay are useful for most economic and environmental analyses. In addition, the basic performance measures are key components of the recommended measures of effectiveness for evaluating ATDM. The remaining performance measures are designed to address three key objectives of ATDM:

1. To improve facility/system productivity;
2. To improve facility/system efficiency; and
3. To improve reliability.

3.4 Identifying Temporal Scope for the Performance Measure Computation

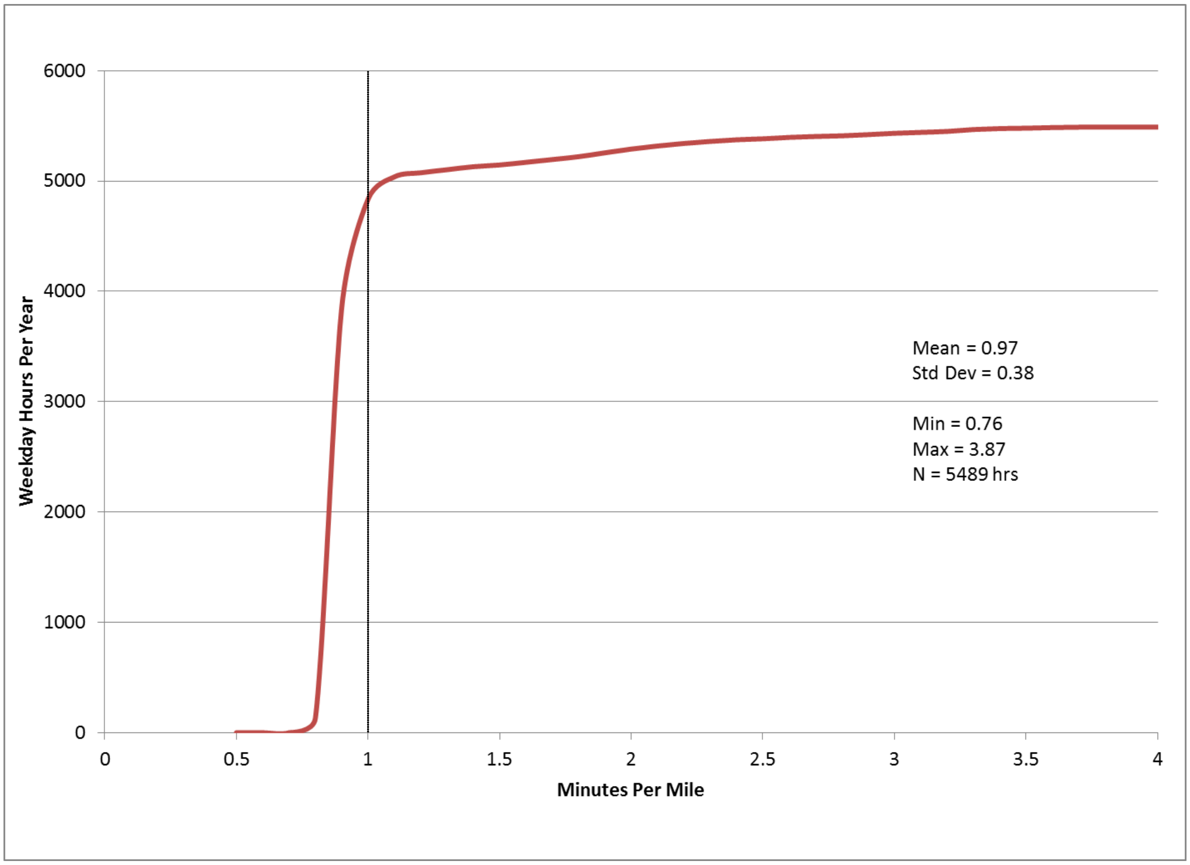
A typical HCM analysis focuses on facility performance for a single peak hour or a single peak period. An ATDM Analysis must consider how the facility performance will vary under varying weather, demand, and incident conditions over the course of one or more years. Thus, while a traditional HCM analysis is unidimensional, an ATDM Analysis must be multidimensional to capture the true performance benefits of ATDM. The methodology simply extends HCM analysis to cover all the possible conditions that influence travel, and combines them into a composite picture of facility performance.

When setting the temporal scope (hours of the day, days of the weeks, and weeks of the year) of an ATDM analysis it is easy to overwhelm the critical performance results by mixing them in with hours and days when there is no congestion. Thus just as an HCM analysis usually focuses on the peak period of a weekday, an ATDM analysis should focus on the peak period, but over all of the weekdays in the year.

The key to the ATDM analysis is to select a temporal range for the analysis (such as the morning or evening peak period for all nonholiday weekdays in a year) that is appropriate for the agency's goals for facility operation. If the goal is to improve weekend and holiday performance, then weekends and holidays should be selected for the ATDM analysis. If the goal is to improve weekday performance then weekdays when the greatest demands are routinely placed on the facility (the morning and/or evening peak periods) should be selected for the analysis.

As shown in Figure 4 for U.S. 101 in Novato, California (San Francisco Bay area), when 24 hours a day are considered for every nonholiday weekday in the year, only 489 out of the 5,489 hours of the year (9%) are congested. The other 91% of the time, ATDM would have little effect on congestion and reliability (although may still have a positive effect on safety) since the facility is not congested. In addition, the vast majority of these uncongested hours are when there are very few people on the road (overnight). To better reflect the experience of the driving public, the hours should be weighted according to the number of people experiencing the condition.

Figure 4: U.S. 101 Weekday Travel Time Rate Distribution (24 hours/day)



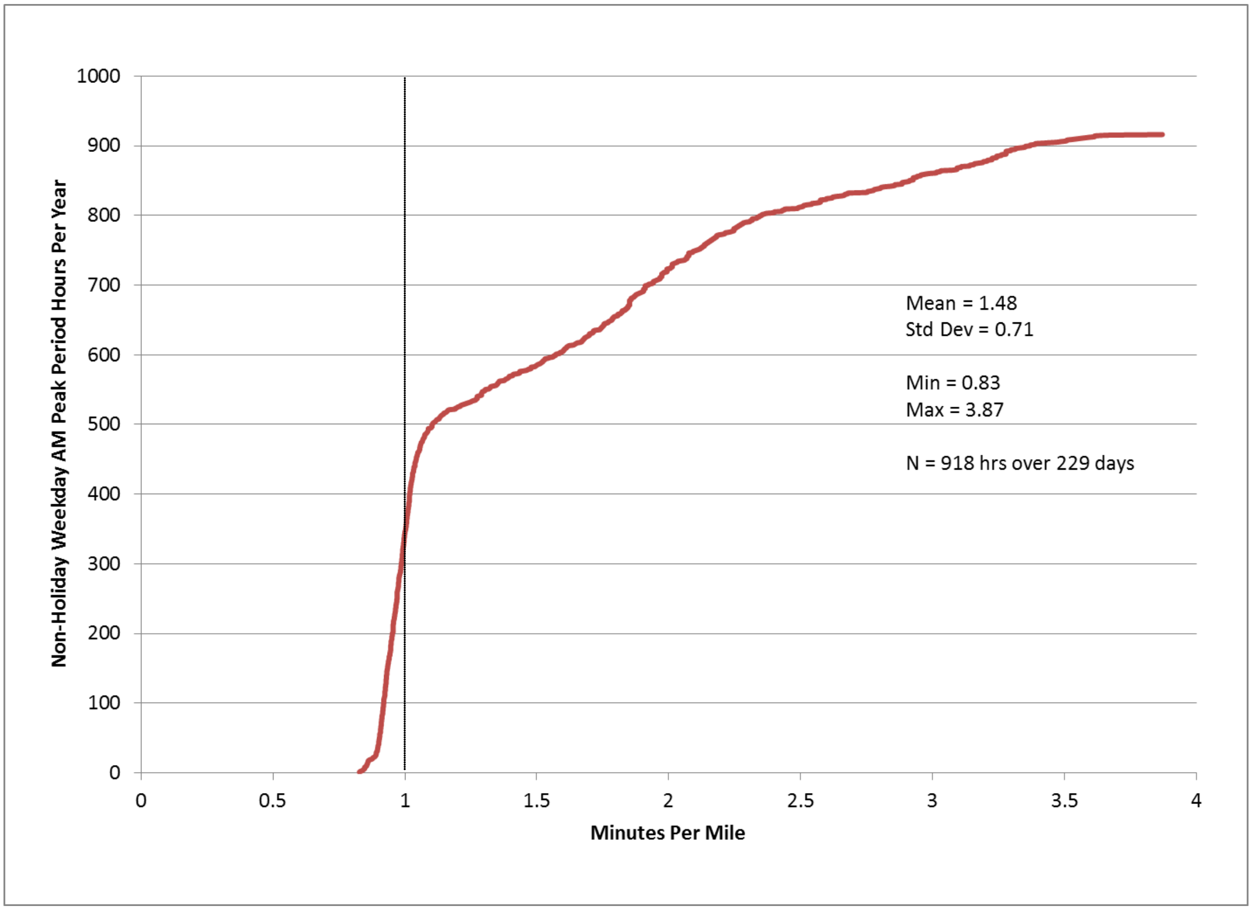
Source: Cambridge Systematics, Inc.

A more useful method for evaluating ATDM is to focus instead on the peak period (or periods) of each day when most drivers are experiencing the condition and when facility performance is most sensitive to minor changes in demand, weather, and incidents.

Figure 5 shows the same U.S. 101 facility performance, but this time focused only on the morning four-hour peak period (6-10 AM) when conditions are most unstable. During the AM peak period demands are more stable so it is more to accurate compare performance across hours and days, without weighting the hours by the volumes.

In this case fully 45% of the hours in the ATDM analysis temporal range are subject to congestion and will be valuable targets of ATDM improvements.

Figure 5: U.S. 101 Weekday AM Peak Period Travel Time Rate Distribution



Source: Cambridge Systematics, Inc.

3.5 Example Performance Characteristics of Facilities

There is little experience at this point in time to guide agencies in the determination of acceptable and unacceptable levels of system performance in terms of the recommended performance measures for evaluating ATDM investments: Average Speed, Average Delay, the PTI, and the 80th Percentile Travel Time Index. For reference, field measurements from several data sources (roadway detectors deployed for operations and private vendor-supplied travel times) were used to develop performance profiles for several U.S. highway facilities; see Tables 2 and 3. A few notes on these tables:

- The AM period is 7:00 AM to 9:00 AM, the mid-day period is 11:00 AM to 2:00 PM, and the PM period is 4:00 p.m. to 6:00 PM. The length of the time period chosen will have a substantial effect on the measures.
- TTI is the Travel Time Index, the mean travel time divided by the free-flow travel time.
- BTI is the Buffer Time Index, computed as the 95th percentile travel time minus the mean travel time, all divided by the mean travel time. It is a measure of reliability.
- PTI is the Planning Time Index, the 95th percentile travel time divided by the free-flow travel time.

Table 2: Typical Performance Measures U.S. Freeways

Location	Route	Length (mi)	FFS (mph)	Direction	Period	Avg Travel Time (min)	TTI	BTI	PTI
Delaware	I-495	11.5	65	NB	AM	11.0	1.03	0.05	1.08
Delaware	I-495	11.6	65	SB	AM	11.1	1.03	0.05	1.07
Delaware	I-95	13.4	60	NB	AM	14.6	1.10	0.25	1.37
Delaware	I-95	13.1	61	SB	AM	13.5	1.05	0.08	1.13
Los Angeles	I-10	4.6	64	EB	AM	4.5	1.06	0.06	1.12
Los Angeles	I-10	4.6	65	WB	AM	4.5	1.08	0.06	1.14
Los Angeles	I-210	4.6	66	EB	AM	4.9	1.17	0.35	1.57
Los Angeles	I-210	4.6	69	WB	AM	4.6	1.16	0.35	1.57
Maryland	I-495ES	26.5	63	SB	AM	28.0	1.10	0.29	1.42
Maryland	I-495ES	26.7	62	NB	AM	31.1	1.20	0.42	1.71
Maryland	I-495WS	15.4	60	NB	AM	18.3	1.19	0.41	1.68
Maryland	I-495WS	15.3	61	SB	AM	26.9	1.78	0.53	2.71
Pennsylvania	I-76	3.7	51	EB	AM	4.7	1.08	0.13	1.22
Pennsylvania	I-76	3.6	49	WB	AM	6.5	1.49	1.05	3.06
Philadelphia	I-76	3.7	51	EB	AM	4.7	1.08	0.13	1.22
Philadelphia	I-76	3.6	49	WB	AM	6.5	1.79	1.05	3.06
Sacramento	U.S. 50	6.0	69	EB	AM	5.7	1.10	0.15	1.27
Sacramento	U.S. 50	6.0	71	WB	AM	6.2	1.21	0.47	1.78
Sacramento	I-80	12.4	68	EB	AM	11.5	1.06	0.07	1.14
Sacramento	I-80	12.4	67	WB	AM	12.0	1.09	0.08	1.17
San Diego	I-5	10.6	71	NB	AM	11.1	1.23	0.46	1.81
San Diego	I-5	10.6	72	SB	AM	9.1	1.02	0.05	1.07
San Diego	I-15	3.9	70	NB	AM	4.7	1.41	0.49	2.10
San Diego	I-15	3.9	69	SB	AM	7.3	1.58	0.48	3.38
San Francisco	I-880	4.6	71	NB	AM	4.6	1.17	0.26	1.47
San Francisco	I-880	4.8	67	SB	AM	8.2	1.92	0.86	3.57
San Francisco	I-680	4.2	66	NB	AM	4.8	1.26	0.53	1.92
San Francisco	I-680	4.7	65	SB	AM	5.2	1.21	0.23	1.49
Delaware	I-495	11.5	65	NB	MID	11.0	1.03	0.04	1.07
Delaware	I-495	11.6	65	SB	MID	11.3	1.05	0.06	1.11
Delaware	I-95	13.4	60	NB	MID	13.9	1.05	0.15	1.20
Delaware	I-95	13.1	61	SB	MID	13.8	1.08	0.24	1.34
Los Angeles	I-10	4.6	64	EB	MID	4.5	1.06	0.09	1.15
Los Angeles	I-10	4.6	65	WB	MID	4.5	1.08	0.06	1.14
Los Angeles	I-210	4.6	66	EB	MID	4.8	1.16	0.13	1.32
Los Angeles	I-210	4.6	69	WB	MID	4.4	1.10	0.07	1.18
Maryland	I-495ES	26.5	63	SB	MID	27.2	1.07	0.23	1.31

Table 2: Typical Performance Measures U.S. Freeways (continued)

Location	Route	Length (mi)	FFS (mph)	Direction	Period	Avg Travel Time (min)	TTI	BTI	PTI
Maryland	I-495ES	26.7	62	NB	MID	28.2	1.09	0.30	1.42
Maryland	I-495WS	15.4	60	NB	MID	20.5	1.34	1.01	2.69
Maryland	I-495WS	15.3	61	SB	MID	19.8	1.30	0.74	2.26
Pennsylvania	I-76	3.7	51	EB	MID	5.0	1.13	0.23	1.39
Pennsylvania	I-76	3.6	49	WB	MID	6.2	1.43	1.06	2.95
Philadelphia	I-76	3.7	51	EB	MID	5.0	1.13	0.23	1.39
Philadelphia	I-76	3.6	49	WB	MID	6.2	1.72	1.06	2.95
Sacramento	U.S. 50	6.0	69	EB	MID	5.8	1.11	0.08	1.20
Sacramento	U.S. 50	6.0	71	WB	MID	5.9	1.15	0.28	1.47
Sacramento	I-80	12.4	68	EB	MID	11.8	1.09	0.15	1.25
Sacramento	I-80	12.4	67	WB	MID	11.9	1.08	0.06	1.14
San Diego	I-5	10.6	71	NB	MID	9.3	1.03	0.04	1.07
San Diego	I-5	10.6	72	SB	MID	9.5	1.06	0.14	1.21
San Diego	I-15	3.9	70	NB	MID	3.8	1.13	0.09	1.23
San Diego	I-15	3.9	69	SB	MID	4.1	1.24	0.30	1.61
San Francisco	I-880	4.6	71	NB	MID	4.5	1.17	0.31	1.53
San Francisco	I-880	4.8	67	SB	MID	5.6	1.31	0.50	1.96
San Francisco	I-680	4.2	66	NB	MID	4.4	1.15	0.17	1.34
San Francisco	I-680	4.7	65	SB	MID	5.0	1.15	0.10	1.26
Delaware	I-495	11.5	65	NB	PM	11.4	1.06	0.16	1.23
Delaware	I-495	11.6	65	SB	PM	12.0	1.10	0.26	1.39
Delaware	I-95	13.4	60	NB	PM	14.6	1.10	0.18	1.29
Delaware	I-95	13.1	61	SB	PM	16.8	1.30	0.41	1.83
Los Angeles	I-10	4.6	64	EB	PM	5.1	1.20	0.09	1.31
Los Angeles	I-10	4.6	65	WB	PM	4.9	1.16	0.10	1.28
Los Angeles	I-210	4.6	66	EB	PM	4.5	1.08	0.24	1.35
Los Angeles	I-210	4.6	69	WB	PM	4.2	1.06	0.09	1.15
Maryland	I-495ES	26.5	63	SB	PM	33.3	1.31	0.42	1.85
Maryland	I-495ES	26.7	62	NB	PM	33.7	1.31	0.52	1.98
Maryland	I-495WS	15.4	60	NB	PM	41.8	2.73	0.74	4.73
Maryland	I-495WS	15.3	61	SB	PM	30.6	2.02	0.82	3.67
Pennsylvania	I-76	3.7	51	EB	PM	6.0	1.36	0.43	1.94
Pennsylvania	I-76	3.6	49	WB	PM	7.7	1.78	0.85	3.29
Philadelphia	I-76	3.7	51	EB	PM	6.0	1.36	0.43	1.94
Philadelphia	I-76	3.6	49	WB	PM	7.7	1.78	0.85	3.29
Sacramento	U.S. 50	6.0	69	EB	PM	7.0	1.35	0.57	2.12
Sacramento	U.S. 50	6.0	71	WB	PM	7.7	1.51	0.81	2.74

Table 2: Typical Performance Measures U.S. Freeways (continued)

Location	Route	Length (mi)	FFS (mph)	Direction	Period	Avg Travel Time (min)	TTI	BTI	PTI
Sacramento	I-80	12.4	68	EB	PM	13.9	1.28	0.44	1.84
Sacramento	I-80	12.4	67	WB	PM	12.1	1.09	0.20	1.31
San Diego	I-5	10.6	71	NB	PM	9.4	1.05	0.17	1.22
San Diego	I-5	10.6	72	SB	PM	13.1	1.47	0.66	2.45
San Diego	I-15	3.9	70	NB	PM	4.7	1.18	0.35	2.97
San Diego	I-15	3.9	69	SB	PM	3.8	1.14	0.31	1.50
San Francisco	I-880	4.6	71	NB	PM	7.7	1.96	0.75	3.43
San Francisco	I-880	4.8	67	SB	PM	5.8	1.34	0.29	1.73
San Francisco	I-680	4.2	66	NB	PM	6.1	1.59	0.72	2.74
San Francisco	I-680	4.7	65	SB	PM	5.0	1.15	0.09	1.25
	Max	26.7	72.0			41.8	2.73	1.06	4.73
	Min	3.6	49.0			3.8	1.02	0.04	1.07
	Average	8.9	63.8			10.6	1.26	0.35	1.78

Notes: FFS = free-flow speed. TTI = Travel Time Index, BTI = Buffer Time Index. PTI = Planning Time Index

The AM period is 7:00 AM to 9:00 AM, the mid-day period is 11:00 AM to 2:00 PM, and the PM period is 4:00 p.m. to 6:00 PM. The length of the time period chosen will have a substantial effect on the measures.

Table 3: Typical Reliability Statistics for U.S. Arterials

Location	Roadway	Length	FFS	Dir	Period	Avg Travel Time	TTI	BTI	PTI
Chula Vista	Telegraph Canyon	4.4	45	EB	AM	6.19	1.06	0.18	1.24
Chula Vista	Telegraph Canyon	4.4	45	WB	AM	6.57	1.12	0.27	1.42
Delaware	U.S. 202	3.8	42	NB	AM	6.97	1.28	0.21	1.55
Delaware	U.S. 202	3.9	44	SB	AM	6.52	1.20	0.17	1.41
Maryland	HWY 175	7.4	38	NB	AM	13.92	1.20	0.10	1.32
Maryland	HWY 175	7.4	38	SB	AM	14.00	1.21	0.11	1.35
Maryland	HWY 193	5.9	33	EB	AM	13.75	1.26	0.15	1.45
Maryland	HWY 193	5.9	33	WB	AM	13.72	1.27	0.20	1.52
Maryland	HWY 198	10.1	42	EB	AM	16.51	1.13	0.10	1.24
Maryland	HWY 198	10.2	41	WB	AM	16.95	1.15	0.10	1.27
Maryland	HWY 355	4.2	30	NB	AM	10.37	1.23	0.13	1.38
Maryland	HWY 355	4.2	30	SB	AM	12.57	1.49	0.43	2.13
Maryland	RANDOLPH	6.7	35	EB	AM	14.13	1.22	0.12	1.36
Maryland	RANDOLPH	6.7	35	WB	AM	15.28	1.31	0.31	1.71
Maryland	U.S. 40	4.1	41	EB	AM	7.00	1.16	0.11	1.29
Maryland	U.S. 40	4.2	39	WB	AM	8.50	1.29	0.43	1.85
Pennsylvania	HWY 611	3.4	20	NB	AM	13.26	1.29	0.22	1.58
Pennsylvania	HWY 611	3.3	19	SB	AM	12.89	1.25	0.13	1.41
Pennsylvania	I-76	3.7	51	EB	AM	4.74	1.08	0.13	1.22
Pennsylvania	I-76	3.6	49	WB	AM	6.45	1.49	1.05	3.06
Pennsylvania	U.S. 1	8.0	33	NB	AM	19.68	1.36	0.22	1.67
Pennsylvania	U.S. 1	7.6	32	SB	AM	18.18	1.29	0.18	1.52
Philadelphia	HWY 611	3.4	20	NB	AM	13.26	1.29	0.22	1.58
Philadelphia	HWY 611	3.3	19	SB	AM	12.89	1.25	0.13	1.41
S. Carolina	U.S. 378	5.5	44	EB	AM	8.61	1.16	0.11	1.29
S. Carolina	U.S. 378	5.4	45	WB	AM	8.37	1.16	0.13	1.31
Chula Vista	Telegraph Canyon	4.4	45	EB	Mid	6.27	1.07	1.15	1.23
Chula Vista	Telegraph Canyon	4.4	45	WB	Mid	6.46	1.10	0.17	1.28
Delaware	U.S. 202	3.8	42	NB	Mid	7.28	1.34	0.22	1.63
Delaware	U.S. 202	3.9	44	SB	Mid	6.93	1.28	0.15	1.47
Maryland	HWY 175	7.4	38	NB	Mid	13.93	1.20	0.10	1.33
Maryland	HWY 175	7.4	38	SB	Mid	14.17	1.23	0.13	1.38
Maryland	HWY 193	5.9	33	EB	Mid	14.29	1.31	0.16	1.52
Maryland	HWY 193	5.9	33	WB	Mid	13.99	1.29	0.15	1.49
Maryland	HWY 198	10.1	42	EB	Mid	17.13	1.18	0.10	1.29
Maryland	HWY 198	10.2	41	WB	Mid	17.47	1.18	0.08	1.27
Maryland	HWY 355	4.2	30	NB	Mid	12.02	1.42	0.31	1.87

Table 3: Typical Reliability Statistics for U.S. Arterials (continued)

Location	Roadway	Length	FFS	Dir	Period	Avg Travel Time	TTI	BTI	PTI
Maryland	HWY 355	4.2	30	SB	Mid	13.07	1.55	0.30	2.01
Maryland	RANDOLPH	6.7	35	EB	Mid	14.22	1.23	0.11	1.36
Maryland	RANDOLPH	6.7	35	WB	Mid	14.62	1.25	0.14	1.42
Maryland	U.S. 40	4.1	41	EB	Mid	7.44	1.23	0.20	1.47
Maryland	U.S. 40	4.2	39	WB	Mid	8.01	1.22	0.17	1.42
Pennsylvania	HWY 611	3.4	20	NB	Mid	14.12	1.38	0.17	1.61
Pennsylvania	HWY 611	3.3	19	SB	Mid	13.78	1.34	0.22	1.63
Pennsylvania	I-76	3.7	51	EB	Mid	4.95	1.13	0.23	1.39
Pennsylvania	I-76	3.6	49	WB	Mid	6.20	1.43	1.06	2.95
Pennsylvania	U.S. 1	8.0	33	NB	Mid	19.23	1.33	0.15	1.53
Pennsylvania	U.S. 1	7.6	32	SB	Mid	19.02	1.35	0.17	1.58
Philadelphia	HWY 611	3.4	20	NB	Mid	14.12	1.38	0.17	1.61
Philadelphia	HWY 611	3.3	19	SB	Mid	13.78	1.34	0.22	1.63
S. Carolina	U.S. 378	5.5	44	EB	Mid	8.88	1.20	0.11	1.33
S. Carolina	U.S. 378	5.4	45	WB	Mid	8.78	1.22	0.15	1.40
Chula Vista	Telegraph Canyon	4.4	45	EB	PM	6.71	1.14	0.18	1.35
Chula Vista	Telegraph Canyon	4.4	45	WB	PM	6.73	1.15	0.18	1.35
Delaware	U.S. 202	3.8	42	NB	PM	7.42	1.36	0.19	1.62
Delaware	U.S. 202	3.9	44	SB	PM	6.84	1.26	0.13	1.43
Maryland	HWY 175	7.4	38	NB	PM	14.20	1.23	0.11	1.36
Maryland	HWY 175	7.4	38	SB	PM	14.81	1.28	0.16	1.49
Maryland	HWY 193	5.9	33	EB	PM	16.39	1.50	0.22	1.83
Maryland	HWY 193	5.9	33	WB	PM	15.67	1.45	0.17	1.69
Maryland	HWY 198	10.1	42	EB	PM	18.53	1.27	0.18	1.50
Maryland	HWY 198	10.2	41	WB	PM	17.81	1.21	0.09	1.32
Maryland	HWY 355	4.2	30	NB	PM	14.03	1.66	0.27	2.11
Maryland	HWY 355	4.2	30	SB	PM	13.47	1.60	0.18	1.89
Maryland	RANDOLPH	6.7	35	EB	PM	16.11	1.39	0.19	1.65
Maryland	RANDOLPH	6.7	35	WB	PM	14.33	1.23	0.10	1.36
Maryland	U.S. 40	4.1	41	EB	PM	9.40	1.56	0.64	2.55
Maryland	U.S. 40	4.2	39	WB	PM	8.04	1.22	0.16	1.41
Pennsylvania	HWY 611	3.4	20	NB	PM	13.22	1.29	0.15	1.48
Pennsylvania	HWY 611	3.3	19	SB	PM	13.19	1.28	0.14	1.46
Pennsylvania	I-76	3.7	51	EB	PM	5.98	1.36	0.43	1.94
Pennsylvania	I-76	3.6	49	WB	PM	7.72	1.78	0.85	3.29
Pennsylvania	U.S. 1	8.0	33	NB	PM	19.63	1.36	0.13	1.53
Pennsylvania	U.S. 1	7.6	32	SB	PM	21.31	1.52	0.19	1.80
Philadelphia	HWY 611	3.4	20	NB	PM	13.22	1.29	0.15	1.48

Table 3: Typical Reliability Statistics for U.S. Arterials (continued)

Location	Roadway	Length	FFS	Dir	Period	Avg Travel Time	TTI	BTI	PTI
Philadelphia	HWY 611	3.3	19	SB	PM	13.19	1.28	0.14	1.46
S. Carolina	U.S. 378	5.5	44	EB	PM	9.22	1.24	0.13	1.41
S. Carolina	U.S. 378	5.4	45	WB	PM	8.81	1.22	0.14	1.39
	Max	10.2	51			21.31	1.78	1.15	3.29
	Min	3.3	19			4.74	1.06	0.08	1.22
	Average	5.4	36			12.02	1.29	0.22	1.57

Notes: FFS = free-flow speed. TTI = Travel Time Index, BTI = Buffer Time Index. PTI = Planning Time Index

The AM period is 7:00 AM to 9:00 AM, the mid-day period is 11:00 AM to 2:00 PM, and the PM period is 4:00 p.m. to 6:00 PM. The length of the time period chosen will have a substantial effect on the measures.

4 Overview of ATDM Analysis Methodology

4.1 Overview

The methodology for capacity and operations analysis of ATDM presented in this Guide is designed to provide estimates of the effects of ATDM strategies on person throughput, mean facility or system travel time (and therefore delay), and facility or system travel time reliability for two conditions:

- Before implementation of ATDM Strategy; and
- After implementation of the ATDM strategy; both "opening day" conditions as well as equilibrium conditions (3 to 6 months after implementation) can be analyzed.

The **before conditions** are used to calibrate and error-check the selected traffic operations models to be used to estimate maximum person throughput, mean travel time and travel time reliability. Depending on the availability of "before" information on counts, incidents, weather, mean travel time, and reliability, the calibration can be relatively simple or quite sophisticated.

After conditions predict how facility throughput, mean travel times and travel time reliability will change after implementation of the ATDM strategy. Two levels of "after" analysis are provided: 1) "opening day" conditions, which represent what happens immediately after implementation and 2) equilibrium conditions which represent conditions travel after travelers have had a chance to become familiar with the facility's new performance levels. That is, travelers have had a chance to shift trip starting times, shift routes, shift destinations, and shift modes in response to the new performance levels. Equilibrium conditions would typically be experienced 3 to 6 months after activation of the ATDM strategy.

For longer term forecasts of the benefits of investing in ATDM strategies (say 20 years or more), the three stages of analysis (before, opening day, long term) are repeated but starting with 20 year forecasts of demand as the base, before condition. The opening day analysis is used to estimate the effects of ATDM on operations in the future. The Equilibrium analysis is then used to equilibrate the demand changes that would occur with ATDM.

The ATDM Analysis Methodology is designed to be applied to a system of highways or a single highway facility. Its capabilities are determined by the tool selected by the analyst for computing the travel time effects of ATDM. For example, ATDM evaluations using the Highway Capacity Manual (HCM) will be limited to single freeway or single urban arterial facilities until such time as the HCM provides systems analysis capabilities. An ATDM analysis using the recommended methodology in combination with a microsimulation model will be able to perform systems evaluations.

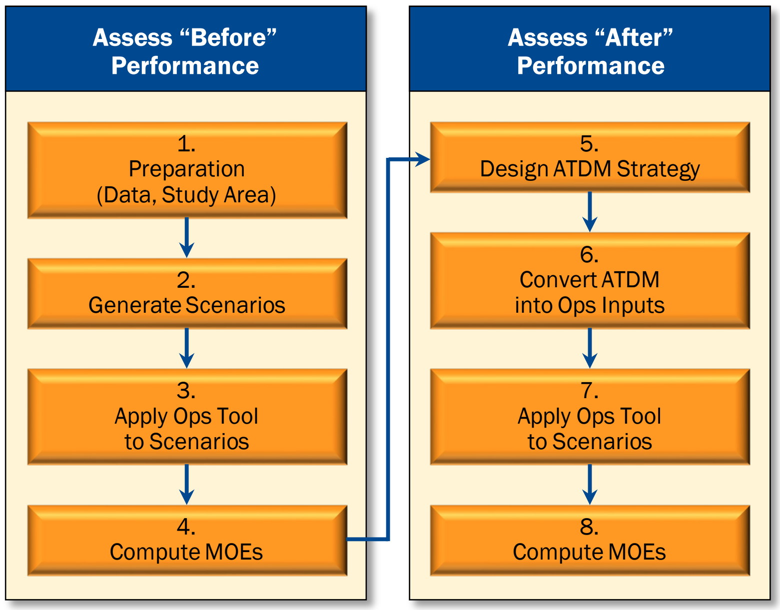
A flowchart of the analysis within the ATDM Analysis methodology is given in Figure 6. The stages of the analysis and the major steps of the analysis are summarized below.

4.2 The "Before ATDM" Analysis

1. Preparatory Steps: This first task consists of setting the scope and purpose of the analysis, defining the target study area, and collecting data.
2. Generate Scenarios: Using historic data on demand, incidents, and weather, a set of demand and capacity scenarios are generated against which to evaluate current conditions and to test the new ATDM strategy. This is the "before" condition.

3. Apply Selected Operations Analysis Tool to Scenarios: The appropriate operations analysis tool (HCM, simulation, etc.) is used to evaluate facility operations for each scenario. Each scenario consists of a given total demand level for the overall peak period, and a given incident and weather condition. This same analysis tool is applied for the Before, Opening Day, and Long-Term Demand Analysis conditions. The demands input to the operations analysis tool will vary according to the condition being evaluated.
4. Compute MOEs (Performance Measures): The results output by the operations analysis tool are combined to yield the desired throughput, delay, and travel time reliability strategies of effectiveness for the "before" condition.

Figure 6: Flow Chart of ATDM Analysis Process



Source: Cambridge Systematics, Inc.

4.3 The "After ATDM" Analysis

5. Design ATDM Strategy: Based on an assessment of the "before" conditions and an identification of the relative contribution of weather, demand, incidents, and work zones to the undesirable performance of the facility or system, the analyst selects and designs the ATDM strategy that he or she wishes to test. If ATDM is already in place for the before condition, then the analyst identifies the changes in the existing ATDM strategy to be tested.
6. Convert ATDM Strategy into Operations Analysis Tool Inputs: The ATDM strategy to be evaluated must be converted into the appropriate demands, capacities, and control inputs required by the operations analysis tool for each specific scenario. This is a key part of the process – the user must be able to translate the effect of an ATDM strategy into the inputs used by the analytical engine.
7. Apply Selected Operations Analysis Tool to Scenarios (Opening Day): The same operations analysis tool as was used in the "before" analysis is used to evaluate the "after" performance. Opening day demands are held essentially constant at this stage with the exception that drivers are assumed to cooperate with the new controls in effect (wait for ramp meters, obey new speed limits, etc.) and take advantage of any new capacity provided (simple lane shifts, but no route, time-of-day, or mode shifts). These are the demand changes estimated to occur on "Opening Day" prior to travelers experiencing or recognizing that the travel time has changed on the facility.

8. Compute MOEs (Opening Day): The results output by the operations analysis tool for Opening Day are combined to yield the desired MOEs. The "after" results are assessed by the analyst to determine if the ATDM strategy should be fine-tuned and reevaluated.

4.4 The "Equilibrium Effects of ATDM" Analysis

The equilibrium effects of ATDM come into play as travelers on other facilities in the area recognize the time and reliability savings of the ATDM improvements on the subject facility and shift their route choice, time-of-day choice, and their mode choice to take advantage of the improved operations on the subject facility. For the purposes of estimating the benefits of ATDM investments it is not strictly necessary to account for the equilibrium effects of ATDM, because travelers drawn to the facility from other facilities (or modes or times of day) do so because they also experience a net benefit from the ATDM improvements to the subject facility. In addition, their leaving the other facilities also improves the operation of the other facilities for those drivers remaining on the other facilities.

Accounting for the equilibrium effects of ATDM is important when one wishes to obtain a more accurate estimate of facility performance after drivers in the area have adapted to the improved conditions. The procedure for equilibrating the estimated facility performance with ATDM is described in Appendix M: The Equilibrium Effects of ATDM.

5 Detailed Methodology: Step-by-Step

The ATDM Analysis methodology proceeds in two stages:

- The “Before” Analysis (Steps 1-4 on Figure 6); and
- The “After” Analysis (Steps 5-8 on Figure 6).

The analysis approach employs a simplified version of the SHRP 2-L08 project methodology (Vandehey, Ryus, Bonneson, Rouphail, Margiotta, & Dowling, 2013) to generate demand, weather, and incident scenarios for the “before” ATDM condition. The ATDM method adds the ability to generate work zone scenarios to the basic SHRP 2-L08 methodology. For the two “after” conditions (opening day and long-term) the ATDM method creates new procedures to test the effects of ATDM strategies on facility performance and reliability. The “Long-Term” analysis takes into account the longer-term demand effects that do not take effect immediately on opening day for the ATDM strategy.

Limitations Inherent in Highway Capacity Manual Methods

The Highway Capacity Manual (HCM) methodologies are currently limited to at most a single direction of a single freeway including ramps, or a two directions of an urban street (including intersections but excluding cross-street performance). The HCM methodologies currently available for the evaluation of rural multilane or two-lane highway performance do not allow for the multi-segment, and multi-time slice evaluations necessary for evaluating ATDM strategies.

Thus the ATDM Analysis method cannot currently be applied to rural multilane and two-lane highways. In addition, the method cannot currently be applied to corridors or multiple facility analysis without substituting an alternative tool for the HCM analysis tool (see Chapter 7, Use of Alternative Tools).

5.1 Step 1: Preparation

This section presents the recommended preparatory steps to apply the procedures for estimating the effect of ATDM strategies on travel time reliability and person throughput for a single facility.

The two key tasks to be accomplished in this preparatory step are:

- Establish ATDM analysis purpose, scope and approach; and
- Acquire and process weather, incident, and demand data.

Establish Purpose, Scope, and Approach for ATDM Analysis

Overview

The purpose, scope and approach for the ATDM Analysis are established at the start. The agency’s goals for ATDM operation are identified. Measures of effectiveness (performance measures) are selected for measuring achievement of the agency’s goals. Thresholds for acceptable performance are determined to help guide the selection of ATDM improvement alternatives and investment levels. The range of ATDM investment strategies for evaluation is identified. The scope of the analysis and the analysis approach are selected for performing the Analysis.

Candidate ATDM goals, MOEs, candidate strategies are covered elsewhere in this Guide:

- Chapter 2 discusses setting agency goals for ATDM operations.
- Chapter 2 discusses of appropriate MOEs for measuring the success of ATDM at achieving agency goals and methods for determining thresholds of acceptable performance.
- Chapter 3 discusses ATDM strategies and improvement options.
- Appendix L: Designing an ATDM Program, provides some introductory information on ATDM program design options.

The determination of the scope of the analysis and the analysis approach are described below.

Geographic and Temporal Scope of Analysis

The ATDM Analysis methodology is designed to be applied to a system of highways or a single highway facility. The geographic coverage of the evaluation will be determined by the agency's ATDM Analysis goals which in turn will determine the appropriate operations analysis tool to be used in the analysis. See Table 4 for definitions of key terms used in this section.

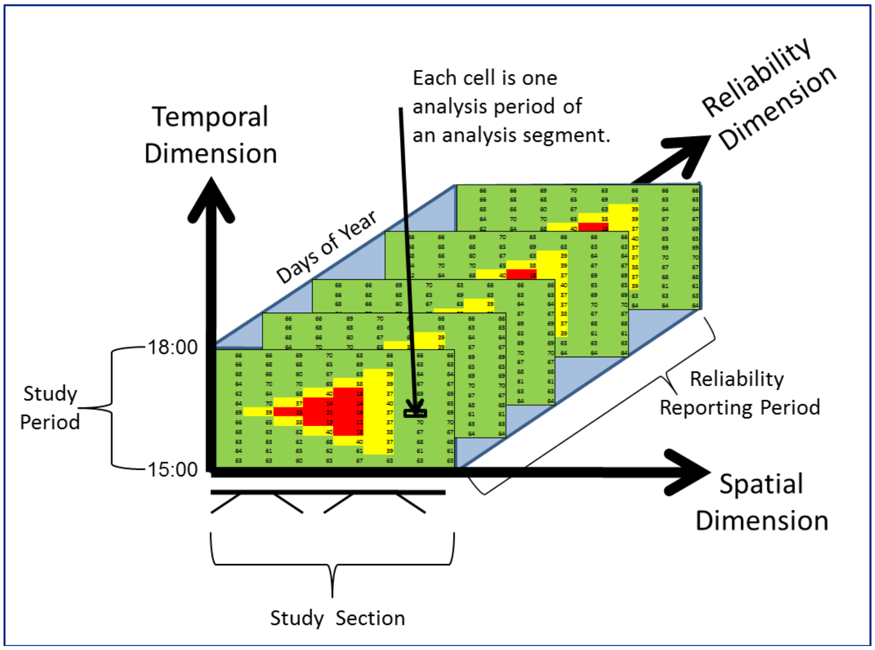
The ATDM Analysis methodology is most accurate when the selected study period starts and ends with uncongested conditions for all scenarios (including weather, incidents, and demand surges). In addition, all congestion under all scenarios should be contained within the length of facility being analyzed, the study section.

However, it is recognized that it is not often feasible to evaluate such large study sections and periods to cover all eventualities, so a reasonable compromise is to select the study period and study section to encompass all of the expected congested locations and times at least 90% of the time for the reliability reporting period (typically one year). The specific objectives of the ATDM investment analysis may suggest higher or lower goals for encompassing congestion within the study limits and times. The choice of study limits should be agreed upon by the stakeholders in the analysis, and the reasons documented for the decision.

Table 4: Definitions of Key Temporal and Geographic Terms

Term	Definition
Reliability Reporting Period:	The selected months, days, hours of year (or years) for the ATDM evaluation. The selected months, days and hours need not be contiguous.
Study Period:	The selected time period within the day for the operations analysis (e.g., AM peak period). A single contiguous set of sequential analysis periods. Several study periods can be evaluated individually by the selected operations analysis tool for any given day or days. Each study period results in one complete operations analysis.
Analysis Periods:	The smallest subdivision of time used by the selected operations analysis tool (for example, if the Highway Capacity Manual is used, the analysis periods are 15 minutes long.)
Study Section:	If a single facility is to be evaluated, then the Study Section is the length of the facility to be evaluated with the selected operations analysis tool. If a network of facilities are to be evaluated, then the Study Section is the portion of the entire network to be evaluated by the selection operations analysis tool.
Analysis Sections:	Geographic subdivisions of the study section that are used by the operations analysis tool to evaluate performance.

Figure 7: Study Section, Study Period, and Reliability Reporting Period



Source: FHWA.

Required Inputs

The minimum required input data for the ATDM Analysis is:

- Sufficient historic demand data and special event data to predict the variability of demand.
- Sufficient historic incident and weather data to predict the variability of capacity.
- Data required by selected traffic operations analysis tool.

Depending on the quality and detail of the available data more or less processing will be required to make it suitable for ATDM Analysis.

Acquisition and Processing of Demand Variability Data

Sufficient demand data must be gathered for the study period for the selected operations analysis tool, the HCM in this case.. The HCM requires 15-minute demands throughout the study period. This might be a single day's data, or it may be the average of several days. In addition, information on how study period demands will vary is required. The best source is archived count data for the facility (or facilities) to be studied. The data should be available for a sufficient number and cross-section of days for the analyst (and any stakeholders involved in the analysis) to be confident that nearly the true variability of demands for the study period has been captured.

Ideally, the analyst would have information on how each 15-minute period demand varied; however, information on how total study period demand varies is sufficient. The analyst then assumes that within peak period variations in demand were captured in the counts used to generate the demands for the traffic operations analysis tool. The between day variation for the entire peak period is then applied as a uniform factor applied to all the 15-minute demands within the peak. As a simplified example, assume the study period was one hour and 15-minute traffic volumes were recorded as 300, 400, 500, and 400 vehicles for total hourly demand of 1,600. Assume also that another scenario includes another day where the overall demand is 75% of the referenced (or seed day) indicated above. If similar 15-minute counts are not available, the methodology can used by applying a factor of 0.75 to each of the seed day 15-minute volumes resulting in assumed demand of 225, 300, 375, 300.

If sufficient archived demand data is not available, the analyst has two options: gather a sample of demands for the peak period over several days, or borrow archived data from a nearby permanent count station. The archived data for a nearby site is used to determine the day-to-day factors to be applied to a single day's count data set for the facility to obtain an approximate estimate of the day-to-day variation in demands for the facility. The use of borrowed or default demand profiles will significantly affect the accuracy of the result. In any case, the demand profile is used as a basis for selecting the demand levels to be used in the overall analysis. For example, the analyst may determine that three levels of demand will be used: the 10th percentile demand, the mean demand, and the 90th percentile. Having the complete demand distribution makes identifying these levels straightforward.

Acquisition and Processing of Special Event Data

For most facilities, special events large enough and close enough to significantly affect facility operation are rare, and can therefore be ignored. Special events can be bundled into the overall demand variability data without requiring special consideration in the ATDM analysis.

For those facilities where major special events are a significant and frequent influence on facility operation then explicit consideration of special events may be warranted. This is especially true if the agency is evaluating ATDM investments specifically designed to address major events. Major league football, baseball, and basketball games, NASCAR races, state fairs, county fairs, and other events where attendance is expected to exceed 10,000 persons at any one time are examples of special events that may be worth evaluating for ATDM investments.

If special events are to be evaluated then the analyst will need to assemble vehicle arrival and departure peaking profiles and directions of travel for each of the events to be evaluated.

For each event the existing or proposed traffic control plan (cones, directional signs, stationing of traffic control officers, parking lot controls, etc.) will need to be defined by the analyst in sufficient detail for coding into the HCM analysis tool.

Acquisition and Processing of Weather Data

Hourly weather reports published by the National Oceanic and Atmospheric Administration (NOAA), Weather Underground, agency road weather information systems (RWIS), and other sources can be used to estimate the frequency of weather types for the facility. For the purposes of the reliability analysis the weather data must specify the historic frequencies of precipitation by type (rain, snow), the precipitation rate, the temperature and the visibility. Weather Underground's historical hourly weather reports (which can be downloaded freely in .csv format from http://www.wunderground.com/) contain all these metrics for almost every town and city in the United States.

The weather data must be classified into the appropriate HCM weather-type categories (light rain, heavy snow, etc.) which is different for freeways and urban streets. After classifying the weather observations, it is possible to compute the probabilities of weather occurrence for each weather type. In one year, there should be 8,760 (365 * 24) hourly observations. The probability of occurrence of a weather type is simply the ratio of the number of observations to 8,760. The annual hours per year of weather by type are used to compute the percentage frequencies (see Table 5).

When multiple weather types are present at the same time in the data, the analyst should classify the weather type as the one with the greatest effect on capacity (see capacity adjustment factors in Table 5 to identify which weather type has the greatest effect. The lower the factor the greater its effect on capacity.

Table 5: Example Weather Data for ATDM Analysis

Weather Type	Range			Speed Adjustment Factor	Capacity Adjustment Factor	Probability
Clear				1.00	1.00	50.0%
Light Rain	> 0.00	<= 0.10	in/hr	0.98	0.98	8.0%
Medium Rain	> 0.10	<= 0.25	in/hr	0.94	0.93	4.0%
Heavy Rain	> 0.25		in/hr	0.93	0.86	2.0%
Very Light Snow	> 0.00	<= 0.05	in/hr	0.89	0.96	6.0%
Light Snow	> 0.05	<= 0.10	in/hr	0.88	0.91	3.0%
Medium Snow	> 0.10	<= 0.50	in/hr	0.86	0.89	2.0%
Heavy Snow	> 0.50		in/hr	0.85	0.76	2.0%
Low Wind	> 10.00	<= 20.00	mph	0.99	0.99	4.0%
High Wind	> 20.00		mph	0.98	0.98	2.0%
Cool	< 50.00	>= 34.00	degrees F	0.99	0.99	2.0%
Cold	< 34.00	>= -4.00	degrees F	0.98	0.98	2.0%
Very Cold	< -4.00		degrees F	0.94	0.91	3.0%
Medium Visibility	< 1.00	>= 0.50	miles	0.94	0.90	2.0%
Low Visibility	< 0.50	>= 0.25	miles	0.93	0.88	2.0%
Very Low Visibility	< 0.25		miles	0.93	0.88	6.0%
Total						100.0%

Note: The minimum required weather data in this chart is the probability of occurrence during the reliability reporting period for each weather type. See Appendix A: Speed/Capacity for Weather, for the derivation of the capacity and speed adjustment factors shown here. Probabilities in this example chart are illustrative, not intended to represent actual conditions anywhere.

Acquisition and Processing of Incident Data

The ATDM Analysis method requires incident data for each of the specific incident type. Table 6 shows mean duration, effect on free-flow speeds, effect on capacity of the remaining open lanes, and the probability of occurrence within the study period (typically the weekday peak period) during the reliability reporting period (typically one year).

The analysis will be most accurate if archived incident data is available for the facility in the requisite detail. Lacking that, the required data can be estimated for existing conditions or forecasted for future conditions using Highway Safety Manual procedures, or the defaults described in Appendix B: Incident Probabilities and Duration. The effects of incidents on free-flow speeds and capacities of the remaining open lanes can be estimated using the defaults described in Appendix C: Speed/Capacity for Incidents.

Table 6: Example Incident Data for ATDM Analysis

Incident Type	Max. Lanes Blocked	Mean Duration (min)	Free-Flow Speed Adjustment Factor	Capacity Adjustment Factor	Probability
None	none	N/A	1.00	1.00	37.53%
Noncrash Incidents	shoulder	30	0.99	0.99	43.42%
	1	30	0.79	0.79	7.66%
	2+	45	0.61	0.61	0.80%
Property Damage Only Crashes	shoulder	30	0.86	0.86	4.90%
	1	45	0.79	0.79	2.44%
	2+	60	0.61	0.61	1.44%
Injury Crashes	shoulder	60	0.86	0.86	0.99%
	1	60	0.79	0.79	0.49%
	2+	60	0.61	0.61	0.29%
Fatal Crashes	shoulder	180	0.86	0.86	0.02%
	1	180	0.79	0.79	0.01%
	2+	180	0.61	0.61	0.01%
Total					100.0%

Note: See Appendix B: Incident Probabilities and Duration, for the derivation of mean incident duration and probabilities. See Appendix C: Speed/Capacity for Incidents, for the derivation of the capacity and speed adjustment factors shown here. Probabilities in this example chart are illustrative, not intended to represent actual conditions anywhere.

Work Zone Data

If work zones are anticipated to be frequent and significant enough to affect annual traffic operations (or the ATDM investments to be tested are anticipated to significantly improve work zone traffic operations) then the analyst should identify the general frequencies of work zone by type, their duration, usual posted speed limits, and the number of lanes to remain open (see Table 7).

Table 7: Example Work Zone Data for ATDM Analysis

Type	Lanes Open	Duration (min)	Cap/Lane	Spd. Adj.	Prob.
None	All	N/A	2,000	1.00	70.0%
Short-Term (1 day or less)	1	240	1,600	0.80	5.0%
	2	240	1,600	0.80	5.0%
	3	240	1,600	0.80	5.0%
Long-Term (>1 day)	1	240	1,400	0.70	5.0%
	2	240	1,450	0.73	5.0%
	3	240	1,500	0.75	5.0%
Total					100.0%

Note: The probabilities in this table are illustrative and are not based on a specific real-world location

The probabilities are the proportion of study periods over the course of the reliability reporting period (typically a year) that are likely to have the designated work zone type and configuration present during the study period.

Work zones in place more than one day are generally classified as "long-term" work zones. On any given day, work zones may or may not be present and active during all or a portion of the daily study period. The duration entered in Table 7 is the number of minutes within the study period when the work zone is active. In this example, the work zone duration of 240 minutes indicates that the work zone is active for the entire 4-hour study period. Shorter work zone periods are certainly possible.

The work zone capacities per lane are shown in Table 7. They can be entered either in units of passenger cars per hour per lane, or vehicles per hour per lane, as long as consistent units are used for capacities throughout the table. The work zone capacity adjustment factors will then be calculated from that data. See Appendix D: Speed/Capacity for Work Zones for derivation of the capacity values and speed adjustments.

Data Required by Selected Operations Analysis Tool

The analyst must consult the users' guide for the selected HCM operations analysis tool to determine what data is required for the tool. The general HCM input requirements for freeway analysis are given in Chapter 10 and subsequent chapters of Volume 2 of the 2010 HCM. For an arterial street analysis the HCM input requirements are given in Chapter 16 and subsequent chapters of Volume 3 of the 2010 HCM.

5.2 Step 2: Generate Scenarios

Overview

Highway capacity analyses are usually performed for near ideal conditions, clear weather, no incidents, recurring peak demand conditions. ATDM is designed to respond to non-ideal conditions. Thus, it is necessary to create scenarios of non-ideal conditions for evaluating the benefits of ATDM.

The ATDM Analysis methodology takes the approach of applying readily available and commonly used Highway Capacity Manual traffic operations analysis tools to static scenarios of demand, weather, and incident conditions rather than developing an entirely new tool. This approach gives the analyst more flexibility in the selection of operations analysis tools that are valid for the specific ATDM strategies under evaluation.

The computational and human resources required to generate inputs, compute performance, error-check, and evaluate results for each scenario set practical limits on the number of scenarios that can be considered for any given ATDM investment analysis. The objective of scenario generation is therefore to identify a sufficient number of varied representative scenarios to accurately evaluate the benefits of the specific ATDM investments that are under consideration without exceeding the resource constraints of the analyst. Because of these limitations, the ATDM Analysis methodology allows up to 30 scenarios to be considered.

As more sophisticated computational tools become available for generating and evaluating scenarios the resource constraints will become less of an issue for ATDM Analysis and numerous scenarios can be evaluated.

The ATDM Analysis method starts out by generating the full array of possible scenarios and then strategically selecting 30 scenarios for HCM analysis, thus enabling rapid analysis of the effects of ATDM strategies on facility performance.

The analysis framework allows for up to:

- 7 demand levels;
- 16 weather conditions;
- 13 incident conditions; and

- 7 work zone conditions.

The available demand, weather, incident, and work zone conditions combine to form 10,192 possible scenarios for analysis. Since it is not feasible with currently available HCM analysis tools for freeway analysis to evaluate this many scenarios the analyst must select 30 of these scenarios for analysis.

Note that the SHRP 2-L08 analysis tools enable the analyst to fully evaluate thousands of scenarios for reliability analysis. In the case of ATDM analysis, it is necessary to limit the number of scenarios to a much smaller number. The need to design and manually apply ATDM strategy responses for each scenario sets a practical limit on the number of scenarios that the analyst will want to create for an ATDM analysis.

The designation of demand, weather, incident, and work zone conditions, their combination into scenarios, and the selection of 30 scenarios for analysis are described in the following subsections.

Identify and Describe Demand Levels

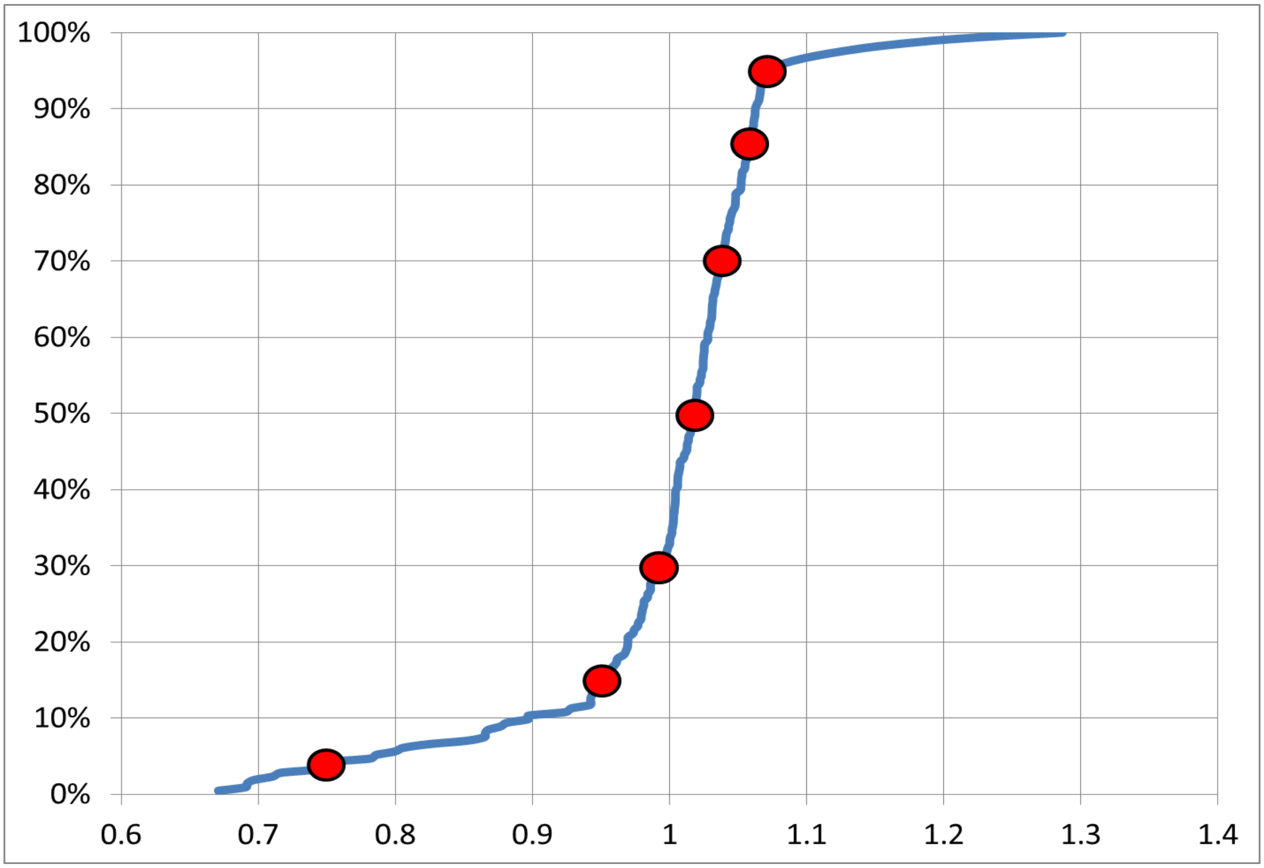
The analyst identifies 7 possible levels of demand that may occur on the facility during the study period over the course of the many days included in the reliability reporting period.

The demand levels are developed from the historical or estimated historic demand data. The total study (peak) period demands for each day in the archive are ranked from lowest to highest. The 5^{th}%, 15^{th}%, 30^{th}%, 50^{th}%, 70^{th}%, 85^{th}%, 95^{th}% highest values are then selected. If a complete (i.e., year-long) demand distribution is not available – either for the specific facility or for a similar one – the analyst needs to develop factors for determining key moments of the distribution that are applied to the short-count traffic data that are available. To do this, continuous volume data from an agency's permanent count locations must be used. The process mirrors that used by traffic monitoring groups to develop daily and seasonal adjustments for daily short-duration counts to get an estimate of average annual daily traffic (AADT). The count locations are grouped by facility type and any other distinguishing factors (e.g., size of urban area). Then a complete distribution profile is developed. The factors assume that the data available to the analyst represent the mean values, so the factors are developed to predict various percentiles of the distribution as a function of the mean. For example, the analysis may show that the 80^{th} percentile demand level is 1.1 times the mean.

Usually, the demand data needed for coding the traffic analysis tool is much more detailed than is available in the archives. Consequently it is usually necessary to collect the more detailed data for the tool for a single day (the seed day) and then factor those single demands to the target percentile demand level. The traffic analysis tool input seed day demands are compared to the target demand levels and factored up or down as necessary to match the target demand level. Unless the analyst has better data available, the same factor is applied to all input demands within the demand level.

The probability of each demand level is computed from the percentile values. The 5^{th} percentile demand is assumed to be representative of the bottom 10% of demands. The 15^{th} percentile demand is representative of demands between the 10^{th} percentile and the 20^{th} percentile, thus it has an estimated 10% probability, etc. (see Figure 8). In this example, the 5^{th}, 15^{th}, 30^{th}, 50^{th}, 70^{th}, 85^{th}, and 95^{th} percentile demand levels are chosen.

Figure 8: Assignment of Probabilities to Percentile Demand Levels



Source: Cambridge Systematics, Inc.

Table 8 shows an example outcome for this step. Seven demand levels have been selected from the demand profile for the facility. For each level a probability has been estimated along with an adjustment factor to be applied to the demands in the HCM seed file to create the demand level.

Table 8: Example Output of Demand Level Selection Step

Demand Level	Probability	Ratio of Percentile Demand to Study Period Average	Ratio of Percentile Demand to Seed File Demand
5th Percentile	10%	0.79	0.77
15th Percentile	10%	0.95	0.93
30th Percentile	20%	0.99	0.97
50th Percentile	20%	1.02	1.00
70th Percentile	20%	1.04	1.02
85th Percentile	10%	1.06	1.04
95th Percentile	10%	1.07	1.05
Total or Average	100%	1.00	0.98

Note: The ratios shown here are illustrative. In this example the day that the analyst selected for counting the demands to be input into the HCM model happened to be about 2% above the average for the year.

In this example, special events have been subsumed within the demand levels selected for analysis. No separate special event demand levels are generated.

Define Weather Conditions

The ATDM Analysis method uses the freeway weather types identified in Chapter 10 (Freeway Facilities) of the 2010 Highway Capacity Manual. The available weather types are listed in Table 5. A total of 16 weather types are available for selection, including: clear weather and various intensities of: rain, snow, wind, temperature and visibility.

Each weather type for a scenario is assumed to apply to the entire study section of the facility for the entire study period.

Define Incident Conditions

The ATDM Analysis method uses the freeway incident types identified in Chapter 10 (Freeway Facilities) of the 2010 Highway Capacity Manual. The available incident types are listed in Table 6. A total of 13 incident types are available for selection, including: no incidents, noncrash incidents (breakdowns, debris), property damage only (PDO) crashes, injury crashes, and fatal crashes.

While incidents may occur randomly at any time and location within the study section and, study period, it is not feasible to evaluate all of these possibilities within 30 scenarios. Consequently, the analyst should select a representative location, start time, and duration for the incident. Since incidents are highly likely to cause congestion that spills over the temporal and geographic limits of the operations analysis tool, it is recommended that the analyst select an incident location near the downstream end of the study section and a start time near the start of the study period to more fully capture the incident effects.

Define Work Zone Conditions

The ATDM Analysis method uses the freeway work zone types identified in Chapter 10 (Freeway Facilities) of the 2010 Highway Capacity Manual. The available work zone types are listed in Table 7. A total of 7 types are available, including: no work zone; short-term work zones keeping 1, 2 or 3 lanes open; and long-term work zones keeping 1, 2, or 3 lanes open.

The ATDM Analysis method is indifferent to the name of the work zone type (long or short). The terms are included to enable the analyst to select different capacity and speed characteristics for long- and short-term work zones.

Work zones are treated as random events similar to incidents in the ATDM Analysis methodology.

While work zones can occur at any time and location within the study section, study period, and reliability reporting period, it is not feasible to evaluate all of these possibilities within 30 scenarios. Consequently, the analyst should select a representative location, start time, and duration for the work zones. Since work zones may cause congestion to spill over the temporal and geographic limits of the operations analysis tool, it is recommended that the analyst select a location near the downstream end of the study section and a start time near the start of the study period for the "representative" work zone to be included in the scenario analysis.

The duration of the work zone is set only for the time that the work zone persists during the study period. Work zone activity outside of the study period is not counted in the estimated duration.

Construction of Scenarios, Computation of Probabilities

The 7 demand levels, 16 weather types, 13 incident types, and 7 work zone types are combined into all possible combinations, resulting in 10,192 possible scenarios for analysis.

The analyst input the individual probabilities for each of the demand levels and types of weather, incidents, and work zones. These marginal probabilities are used to compute the combined probability of each scenario, assuming independence of the types and demand levels.

$$P(d,w,i,wz) = P(d) * P(w) * P(i) * P(wz)$$

Equation 3

Where:

P(d,w,i,wz) = Combined probability of a scenario with demand level "d," weather type "w," incident type "I" and work zone type "wz."

P(d) = Probability of demand level "d" (analyst input).

P(w) = Probability of weather of type "w" (analyst input).

P(i) = Probability of incident type "i" (analyst input).

P(wz) = Probability of work zone type "wz" (analyst input).

While it is not statistically correct to assume that demand, weather, incidents, and work zones are independent, as a first order approximation, the assumption of independence saves the analyst a greater amount of data collection to establish the correlations, and the resulting scenario probabilities give a rough indication of the relative frequency of one scenario compared to another.

The SHRP 2-L08 freeway method partially incorporated some limited correlation between demand and weather, and between weather and incidents by tying scenarios to specific months of the year. The natural correlation between season of the year, demand, weather, and incidents is incorporated into the monthly demand, weather, and incident rates used in the SHRP 2-L08 freeway method. The following equation illustrates this approach.

$$P(m,d,w,i,wz) = P(m,d) * P(m,w) * P(m,i) * P(m,wz)$$

Equation 4

Where:

P(m, d,w,i,wz) = Combined probability of a scenario in month "m," with demand level "d," weather type "w," incident type "I" and work zone type "wz."

P(m,d) = Probability of demand level "d" during month "m" (analyst input).

P(m,w) = Probability of weather of type "w" during month "m" (analyst input).

P(m,i) = Probability of incident type "i" during month "m" (analyst input).

P(m,wz) = Probability of work zone type "wz" during month "m" (analyst input).

Selection of 30 Scenarios for HCM Analysis

At this point in the process, if all 7 demand levels, 16 weather types, 13 incident types, and 7 work zone types are considered, 10,192 possible scenarios for analysis will be generated. The analyst must then select 30 of those scenarios for analysis.

The need to reduce the analysis to 30 scenarios is not driven so much by computational requirements. Computer programs, properly written, can evaluate 10,192 scenarios in minutes if not seconds on today's personal computers.

The need to reduce the analysis to 30 scenarios is driven more by the need of the analyst to fully specify the ATDM strategies to be employed individually for each scenario. At this point in time, given the early stage of ATDM development in the country, it is necessary to give the analyst complete freedom to specify the ATDM strategies for each and every scenario. Later, as the state of the art matures, it may be possible to write decision-making algorithms that will automatically select the appropriate ATDM strategies for each scenario. The ATDM Analysis method allows the analysts discretion, according to the analyst's objectives for the ATDM analysis: The analyst selects 30 specific combinations of demand levels, weather, incidents, and work zones to be tested. This method guarantees that those combinations will be evaluated for the effects of ATDM. For example, if the analyst is evaluating the benefits of incident management investments, the analyst may wish to focus the scenario selection on those involving incidents. Table 9 illustrates one possible outcome using this method of scenario selection. When one attempts to use 30 scenarios to represent the effects for 10,192 scenarios, some detail must be sacrificed, and the danger of biasing the results in the selection must be recognized.

Table 9: Example Scenario Selection

#	d/c. Adj.	Demand	Weather	Incident	Work Zone	Prob.
1	0.850	Low	Clear	No	None	14.25%
2	1.214	Low	Clear	No	Lng.Trm 1	1.02%
3	1.072	Low	Clear	PDO-1	None	1.14%
4	1.531	Low	Clear	PDO-1	Lng.Trm 1	0.08%
5	0.914	Low	Med. Rain	No	None	1.14%
6	1.306	Low	Med. Rain	No	Lng.Trm 1	0.08%
7	1.152	Low	Med. Rain	PDO-1	None	0.09%
8	1.646	Low	Med. Rain	PDO-1	Lng.Trm 1	0.01%
9	0.934	Low	Lt. Snow	No	None	0.86%
10	1.334	Low	Lt. Snow	No	Lng.Trm 1	0.06%
11	1.261	Med	Clear	PDO-1	None	3.99%
12	1.801	Med	Clear	PDO-1	Lng.Trm 1	0.29%
13	1.000	Med	Clear	No	None	49.89%
14	1.429	Med	Clear	No	Lng.Trm 1	3.56%
15	1.356	Med	Med. Rain	PDO-1	None	0.32%
16	1.937	Med	Med. Rain	PDO-1	Lng.Trm 1	0.02%
17	1.075	Med	Med. Rain	No	None	3.99%
18	1.536	Med	Med. Rain	No	Lng.Trm 1	0.29%
19	1.385	Med	Lt. Snow	PDO-1	None	0.24%
20	1.979	Med	Lt. Snow	PDO-1	Lng.Trm 1	0.02%
21	1.150	High	Clear	No	None	14.25%
22	1.643	High	Clear	No	Lng.Trm 1	1.02%
23	1.450	High	Clear	PDO-1	None	1.14%
24	2.071	High	Clear	PDO-1	Lng.Trm 1	0.08%
25	1.237	High	Med. Rain	No	None	1.14%
26	1.767	High	Med. Rain	No	Lng.Trm 1	0.08%
27	1.559	High	Med. Rain	PDO-1	None	0.09%
28	2.227	High	Med. Rain	PDO-1	Lng.Trm 1	0.01%
29	1.264	High	Lt. Snow	No	None	0.86%
30	2.276	High	Lt. Snow	PDO-1	Lng.Trm 1	0.00%
Average	1.056				Total	100.00%

Note: Scenarios selected to achieve a target mix of conditions. d/c is the demand to capacity ratio.

5.3 Step 3: Apply Operations Model to Scenarios

In this step, the selected HCM operations analysis model is coded, error-checked, and calibrated, as appropriate. The analyst should consult the appropriate user's guide for the selected tool.

The traffic operations analysis tool is applied separately to each scenario to compute predicted segment travel times for the facility under each scenario. For scenarios involving capacity reduction events such as weather, incidents, and work zones, the analyst will need to adjust the coded (or calibrated) capacities in the model to reflect those events.

Quality Control The Seed File

Often the demand inputs, traffic controls, and capacities reflect conditions measured in the field for a single day's peak period (nonpeak periods could also be selected for analysis).[3] The input file(s) for this initial operations model of the facility will be called the "Seed" file. The other scenarios are generated by pivoting off of this seed file. It is critical that this seed file be accurate as feasible, because the entire ATDM evaluation will based on this seed file.

5.4 Step 4: Compute MOEs (Before ATDM)

The MOEs (performance measures) reported by operations analysis tool for each scenario are combined to obtain the total performance statistics for the facility or facilities. Computation details are provided in Appendix E: Measures of Effectiveness.

The performance measures reported for the before condition are listed below:

1. Vehicle-Miles Traveled Demand (VMT-Demand);
2. Vehicle-Miles Traveled Served (VMT-Served);
3. Vehicle-Hours Traveled (VHT);
4. Vehicle-Hours Delay (VHD);
5. System Efficiency: Average System Speed);
6. Traveler Perspective: Vehicle-Hours Delay/Vehicle-Mile Traveled (VHD/VMT); and
7. Reliability: the Planning Time Index (PTI) and the80th Percentile Travel Time Index.

Table 10 shows a typical table of MOEs computed for a "Before" ATDM Analysis. From this table the summary statistics are computed with the results shown in Table 11.

The vehicle-miles demanded is the same as the amount traveled, indicating that all demand is served by the facility. The average speed for the study period over the days of the reliability reporting period is 58.1 mph (about 83% of the 70 mph free-flow speed for the facility. The average delay is 10.6 seconds per mile. The Planning Time Index (95th Percentile TTI) is 1.69. To be 95% confident of arriving on time over the course of a year of weekday PM peak periods, travelers must add an extra 69% to their expected free-flow travel time on the facility.

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[3] Sometimes the analyst has sufficient data to average a few days of data into a "typical" peak period day. Either way, the result is a single representative study period coded into the traffic operations tool.

Table 10: Example MOE Output

Scenario Number	Scenario Probability	Type	VMTD (Demand)	VMTV (Volume)	VHD delay (hrs)	VHT	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Queue (mi)	% 15-mins with LOS=F
1	0.1%		86,794	86,794	83	1,323	0.88	7.0	1.1	65.6	64.3	0.00	0.0%
2	8.6%		86,794	86,794	100	1,340	0.88	7.1	1.1	64.8	63.5	0.00	0.0%
3	1.1%	I	86,794	86,794	85	1,325	0.88	7.0	1.1	65.5	64.3	0.00	0.0%
4	1.1%	I	86,794	86,794	262	1,502	1.70	26.5	1.4	57.8	26.9	1.14	18.8%
5	4.3%	W	86,794	86,794	199	1,439	0.95	7.8	1.1	60.3	58.1	1.14	6.3%
6	17.2%	W	86,794	86,794	216	1,456	0.95	7.9	1.2	59.6	57.4	1.14	6.3%
7	8.6%	WI	86,794	86,794	200	1,440	0.95	7.8	1.2	60.3	58.1	1.14	6.3%
8	0.1%	WI	86,794	86,794	410	1,650	1.82	30.9	1.5	52.6	24.1	1.25	25.0%
9	5.7%	W	86,794	86,794	293	1,533	0.97	8.3	1.2	56.6	54.6	1.25	6.3%
10	10.2%	W	86,794	86,794	311	1,550	0.97	8.4	1.2	56.0	54.0	1.25	6.3%
11	0.0%	I	93,327	93,327	95	1,427	0.95	7.1	1.1	65.4	63.8	1.25	0.0%
12	8.6%	I	93,327	93,327	328	1,659	1.82	30.6	1.4	56.3	24.1	1.38	18.8%
13	5.7%		93,327	93,327	94	1,426	0.95	7.1	1.1	65.5	63.8	1.38	0.0%
14	0.6%		93,327	93,327	112	1,444	0.95	7.2	1.1	64.6	63.0	1.38	0.0%
15	0.4%	WI	93,327	93,327	256	1,587	1.02	8.6	1.2	58.8	51.8	0.51	12.5%
16	0.4%	WI	93,327	93,327	530	1,860	1.96	35.9	1.6	50.2	21.8	1.49	31.3%
17	0.7%	W	93,327	93,327	255	1,586	1.02	8.6	1.2	58.9	51.8	0.51	12.5%
18	17.2%	W	93,327	93,327	274	1,604	1.02	8.7	1.2	58.2	51.2	0.51	12.5%
19	0.2%	WI	93,327	93,327	378	1,708	1.05	9.7	1.3	54.6	46.0	0.66	18.8%
20	5.7%	WI	93,327	93,327	664	1,994	2.00	37.8	1.7	46.8	21.0	1.52	37.5%
21	0.0%		97,060	97,060	102	1,485	0.99	7.1	1.1	65.4	63.4	1.52	0.0%
22	0.1%		97,060	97,060	121	1,504	0.99	7.2	1.1	64.5	62.6	1.52	0.0%
23	0.0%	I	97,060	97,060	104	1,487	0.99	7.1	1.1	65.3	63.4	1.52	0.0%
24	2.1%	I	97,060	97,060	371	1,754	1.90	33.3	1.5	55.3	22.8	1.52	18.8%
25	0.0%	W	97,060	97,060	316	1,697	1.06	9.6	1.2	57.2	46.4	0.79	18.8%
26	0.2%	W	97,060	97,060	335	1,716	1.06	9.7	1.2	56.5	45.9	0.79	18.8%
27	0.0%	WI	97,060	97,060	318	1,699	1.06	9.6	1.2	57.1	46.4	0.79	18.8%
28	0.4%	WI	97,060	97,060	635	2,015	2.04	39.1	1.7	48.2	20.7	1.62	43.8%
29	0.6%	W	97,060	97,060	457	1,819	1.09	10.1	1.3	53.4	44.1	0.80	18.8%
30	0.0%	WI	97,060	97,060	791	2,153	2.08	41.4	1.8	45.1	19.8	1.65	43.8%

Note: VMT = vehicle-miles traveled. VHT = vehicle-hours traveled. VHD = vehicle-hours delay. TTI = Travel Time Index, W = Weather only, I = Incident Only, WI = Weather and Incident

Table 11: Example Summary Statistics for Before ATDM Condition

Measure of Effectiveness	Value	Units
VMT Demanded	22,433,669	Annual veh-miles
VMT Served	22,433,669	Annual veh-miles
VHT -Traveled	386,024	Annual veh-hours
VHD – Delay	65,905	Annual veh-hours delay
Average Speed	58.11	mph
Average Delay	10.58	secs/mile
PTI (95th% TTI)	1.69	

Note: Annual performance of facility during weekday PM peak periods before ATDM

5.5 Step 5: Design ATDM Strategy

Overview

The current state of-the art for ATDM operations is rapidly evolving at this time. New strategies and the logic behind them are being developed, tested, and refined on a daily basis. This section describes a method for organizing the wide variety of possible ATDM system responses to changes in demand, weather, and incident conditions into a condensed menu of response plans, one for each situation suitable for a macroscopic analysis. The purpose of this analysis is to determine the potential operational and performance benefits of different general ATDM management approaches without requiring the analyst to evaluate and test every possible option and determine the precisely optimal decision rules, control settings, and tactics for each real life situation. Thus, this method is not suitable to determine the precise decision rules, control settings, and tactics that are optimal for a range of real life conditions. This method is designed to determine the likely benefits of introducing the control flexibility and responsiveness of ATDM to a facility.

This analysis method consequently condenses the wide variety of ATDM strategies into a simple menu of strategies that the analyst can select from to reflect different levels of investment and responsiveness of the ATDM strategies.

Appendix L: Designing an ATDM Program, provides an introductory overview of ATDM program design options and provides references for further information on ATDM program design.

The ATDM Analysis method currently provides for the analysis of the ATDM strategies listed in Table 12, along with a summary of how the method models each one.

Table 12: ATDM Strategies Currently Addressed by the Methodology

Strategy	Adjustments to Methodology Inputs
Recurring TDM Plan	User assigns demand adjustment factors by demand level
Weather TMP	User assigns change in free-flow speed, capacity, and/or demand adjustment factors for each weather type identified
Traffic Incident (TIM) Plan	Incident Frequency: user adjusts the incident probabilities to reflect reduced number of incidents, for example, such as those due to safety improvements Incident Effects: User specifies adjustments for any of the following factors: VSL presence, free-flow speed, capacity, incident duration, and demand
Work Zone TMP	User specifies adjustments by work zone type for any of the following factors: VSL presence, free-flow speed, capacity, and demand
Variable Speed Limits (VSL)	User specifies the rate of reduction in free-flow speed per half-mile upstream of the incident or work zone
HOV/HOT	User specifies the capacity and usage of the HOV or HOT lane and identifies the scenarios when specific HOV or HOT lane operation policies (for example, HOV lane open to SOVs) are active.
Dynamic Shoulder Lane	User specifies shoulder lane capacity and the policy for opening the lane (e.g., buses only, etc.) for each scenario.
Dynamic Median Lane	User specifies median lane capacity and the policy for opening the lane (e.g., buses only, etc.) for each scenario.
Truck Controls	User specifies the percent of vehicles on the facility that would be affected by a truck ban and identifies the scenarios where such a ban would be implemented.
Ramp Metering	User specifies maximum and minimum metering rates, type of metering (fixed time or dynamic), desired ramp storage limits, demand diversion, and target vehicles per hour per lane for ramp merge areas. User identifies the desired ramp metering strategy for each scenario.

As ATDM develops further more traffic management options will be available for both freeway and nonfreeway/ arterial environment.

Travel Demand Management Strategies For Recurrent Congestion

Travel demand management (TDM) strategies can be everyday strategies designed to reduce recurrent congestion, or they may be incident, weather, and work zone-specific strategies designed to mitigate specific types of events on the facility. Those TDM strategies targeted to specific events will be dealt with as part of the response plans for those specific events. This section focuses on TDM strategies designed to address recurrent congestion.

Travel demand management options for recurring congestion included in the methodology are:

- Congestion pricing strategies, such as specific lane tolling or full facility tolling;
- Travel information strategies including pre-trip services such as web-based information and en-route information such as in-vehicle navigation devices, and changeable message signs; and
- Employer-based TDM strategies reflecting a wide range of employer incentives and disincentives to reduce single occupant vehicle commuting before the vehicle reaches the employer facility.

The various TDM strategies are bundled by the analyst into one or more TDM plans for the facility. The analyst then estimates the combined effects on demand of the strategies within each of the plans.

The analyst identifies the levels of demand when each TDM plan goes into effect. Each TDM plan is assumed to uniformly affect facility-wide demand for the entire study period for the scenario when the TDM plan is in effect.

The analyst may specify a different TDM plan, with a different effect on demand, for each of the 7 possible levels of demand identified by the analyst in the "before" analysis. Table 13 shows an example of TDM Plan coding.

Table 13: Illustrative Coding of TDM Plans for ATDM Analysis

	Demand Level	TDM Plan Demand Adjustment Factor
1	Very Low Demand	0.98
2	Low Demand	0.98
3	Low-Medium Demand	0.97
4	Medium Demand	0.97
5	Medium-High Demand	0.96
6	High Demand	0.96
7	Very High Demand	0.95

Note: Entries are illustrative of a hypothetical TDM plan that becomes more aggressive (adding more TDM strategies) as demand increases, however; values shown are not intended to be representative of actual TDM effects. A value of 1.00 means no change with ATDM. Each row represents a different possible ATDM response for a different recurring demand condition

Weather-Responsive Traffic Management Plan

Weather responsive traffic management (WRTM) plans consist of control strategies, traveler advisory strategies, and treatment strategies:

- Control strategies restrict the vehicles and imposes equipment requirements (such as chains) for vehicles using the facility during adverse weather;
- Traveler advisories include pre-trip and en-route information to advice drivers of weather conditions; and
- Treatment strategies include anti-icing and snow removal strategies among others.

The various weather traffic management strategies are bundled by the analyst into one or more WRTM plans for the facility. The analyst estimates the combined effects of the strategies within each plan on facility demand, capacity, and free-flow speeds. The analyst identifies the weather types when each WRTM plan goes into effect. Each WRTM plan is assumed to uniformly affect the entire facility for the entire study period when the weather type is present and the plan is in effect.

The analyst may specify a different W-TMP plan, with different effects on demand, capacity, and free-flow speeds, for each of the 16 possible weather types identified by the analyst in the "before" analysis. Table 14 shows an example of Weather TMP Plan coding.

Table 14: Illustrative Coding of Weather TMP Plans for ATDM Analysis

Weather Type	Speed Adjust.	Capacity Adjust.	Demand Adjust.
Clear, Fair Weather	1.00	1.00	1.00
Light Rain	1.00	1.00	1.00
Medium Rain	1.00	1.00	1.00
Heavy Rain	1.00	1.00	1.00
Very Light Snow Fall	1.00	1.00	1.00
Light Snow Fall	1.00	1.05	0.90
Medium Snow Fall	0.90	0.95	0.75
Heavy Snow Fall	0.80	0.92	0.50
Low or Light Winds	1.00	1.00	1.00
High Winds	1.00	1.00	1.00
Cool Temperatures	1.00	1.00	1.00
Temperatures Below 34^0 F	1.00	1.00	1.00
Temperatures Below -4^0	1.00	1.00	0.80
Medium Visibility	1.00	1.00	1.00
Low Visibility	1.00	1.00	1.00
Very Low Visibility	0.85	1.00	0.85

Note: Entries are illustrative of the coding capabilities, not intended to represent actual Weather TMP effects. A value of 1.00 means no change with ATDM. Each row represents a different possible ATDM response for a different weather type. Weather dependent speed limits are coded by adjusting the free-flow speed for each weather type.

Traffic Incident Management Plan

The Traffic incident management (TIM plan) consists of site management and control strategies, traveler advisory strategies, plus detection, verification, response and clearance strategies.

- Site management and traffic control include strategies such as: incident command systems (on-site traffic management teams and end of queue advance warning systems); travel information strategies (including pre-trip services such as web-based information and en-route information such as in-vehicle navigation devices, and changeable message signs); detection and verification strategies (including field verification by on-site responders, closed circuit television cameras, enhanced roadway reference markers, enhanced/ automated 911 positioning systems, motorist aid call boxes, and automated collision notification systems);
- Response strategies such as: personnel/equipment resource lists; towing and recovery vehicle identification guides; instant tow dispatch procedures; towing and recovery zone-based contracts; enhanced computer aided dispatch; dual/optimized dispatch procedures; motorcycle patrols; and equipment staging areas/prepositioned equipment; and
- Quick clearance and recovery strategies such as: incident investigation sites; quick clearance laws, policies, and incentives; expedited crash investigations, service patrols, enhanced capability service patrols; and major incident response teams.

The various traffic incident management strategies are bundled by the analyst into one or more TIM plans for the facility. The analyst estimates the combined effects of the strategies within each plan on facility demand, capacity, and free-flow speeds. The analyst identifies the incident types when each TIM plan goes into effect.

Each TIM plan is assumed to uniformly affect demand for the entire facility for the analysis time periods when the incident is present and the TIM plan is in effect. Capacity and free-flow speeds are assumed to be affected by the TIM plan only in the vicinity of the incident, while it is present. Variable speed limits (see next section) are assumed to be in effect (if active) only upstream of the incident and only while the incident is present.

The analyst may specify a different TIM plan, with different effects on demand, capacity, incident duration, and free-flow speeds, for each of the 13 possible incident types identified by the analyst in the “before” analysis (see Table 15). Alternatively, the analyst may apply a particular TIM plan for more than one incident type.

Table 15: Illustrative Coding of TIM Plans for ATDM Analysis

Incident Type	VSL Upstream?	Duration Adjust.	Speed Adjust.	Capacity Adjust.	Demand Adjust.
No Incident	–	1.00	1.00	1.00	1.00
Noncrash Blocking Shoulder	–	0.95	0.95	1.00	1.00
Noncrash Blocking One Lane	Yes	0.95	0.80	1.00	1.00
Noncrash Blocking Two+ Lanes	Yes	0.95	0.80	1.00	1.00
Property Damage Only Crash on Shoulder	–	0.90	0.95	1.00	1.00
PDO Crash Blocking One Lane	Yes	0.90	0.80	1.00	1.00
PDO Crash Blocking Two+ Lanes	Yes	0.90	0.80	1.00	0.95
Injury Crash Blocking Shoulder	–	0.90	0.95	1.00	1.00
Injury Crash Blocking One Lane	Yes	0.90	0.80	1.00	0.95
Injury Crash Blocking Two+ Lanes	Yes	0.90	0.80	1.00	0.90
Fatal Crash Blocking Shoulder	–	0.90	0.95	1.00	1.00
Fatal Crash Blocking One Lane	Yes	0.90	0.80	1.00	0.90
Fatal Crash Block Two+ Lanes	Yes	0.90	0.80	1.00	0.85

Note: Entries are illustrative of the coding capabilities, not intended to represent actual TIM effects. A value of 1.00 means no change with ATDM. Each row represents a different possible ATDM response for a different incident type. VSL = variable speed limit.

Variable Speed Limits (VSL) or Speed Advisories

Variable speed limits may be applied four ways in the analysis methodology.

1. The analyst may specify uniform (constant) reductions in the facility free-flow speed for each of the 7 available demand levels.
2. The analyst may specify uniform (constant) reductions in the facility free-flow speed for each of the 16 possible weather types.
3. The analyst may specify reduced free-flow speed in the vicinity of an incident and specify the graduated reduction in upstream free-flow speeds as traffic approaches the incident, while the incident is active.
4. The analyst may specify reduced free-flow speed in the vicinity of a work zone and specify the graduated reduction in upstream free-flow speeds as traffic approaches the work zone, while the work zone is active.

For VSL when traffic incidents or work zones are present, it is assumed to apply only upstream of the incident or work zone, and only while the incident or work zone is active. The analyst must translate the reduction in speed limit into the equivalent reduction in free-flow speed. For speed advisories, it is assumed that motorists comply with the recommended speed; there is no provision in the methodology to adjust for compliance rate. If the analyst believes this assumption to be untenable, then speed advisories should be selected as a strategy.

Note that the input VSL speed for a segment will be overridden if it violates the HCM 2010 requirement that the free-flow speed be higher than the speed at capacity (which is estimated by the HCM 2010 assuming a density of 45 passenger car equivalents per lane per mile).

Work Zone Traffic Management Plan

The work zone traffic management plan (WZ-TMP) consists of site management and control strategies, and traveler advisory strategies. Site management and control strategies include end of queue advance warning signs, speed feedback signs, and automated speed enforcement, in addition to the conventional work zone traffic management strategies. Travel information strategies including pre-trip services such as web-based information and en-route information such as in-vehicle navigation devices, and changeable message signs.

The various work zone traffic management strategies are bundled by the analyst into one or more WZ-TMP plans for the facility. The analyst estimates the combined effects of the strategies within each plan on facility demand, capacity, and free-flow speeds. The analyst identifies the work zone types when each WZ-TMP plan goes into effect.

Each WZ-TMP plan is assumed to uniformly affect demand for the entire facility for the analysis time periods when the work zone is present and the WZ-TMP plan is in effect. Capacity and free-flow speeds are assumed to be affected by the WZ-TMP plan only in the vicinity of the work zone, while it is present. Work zone triggered variable speed limits (see previous section) are assumed to be in effect (if active) only upstream of the work zone and only while the work zone is present.

The analyst may specify a different WZ-TMP plan, with different effects on demand, capacity, and free-flow speeds, for each of the 7 possible work zone types identified by the analyst in the "before" analysis.

Table 16: Illustrative Demand Adjustment Factor Inputs for TDM Plans

Work Zone Type	VSL Upstream?	Speed Adjust.	Capacity Adjust.	Demand Adjust.
No Work Zone Present	–	1.00	1.00	1.00
Short-Term Work Zone (1) (maintaining one open lane)	–	1.00	1.00	1.00
Short-Term Work Zone (2) (maintaining two open lanes)	–	1.00	1.00	1.00
Short-Term Work Zone (3) (maintaining three open lanes)	–	1.00	1.00	1.00
Long Term Work Zone (1) (maintaining one open lane)	Yes	1.00	1.00	1.00
Long Term Work Zone (2) (maintaining two open lanes)	Yes	1.00	1.00	1.00
Long Term Work Zone (3) (maintaining three open lanes)	Yes	1.00	1.00	1.00

Note: Entries are illustrative of the coding capabilities, not intended to represent actual Work Zone TMP effects. A value of 1.00 means no change with ATDM. Each row represents a different possible set of ATDM strategies for a different work zone type. VSL = variable speed limit.

HOV/HOT Lane Management Strategies

The ATDM Analysis methodology is set up to evaluate 5 possible HOV and HOT (Express) lane management strategies in response to demand, weather, incidents, and work zones.

1. No change to "before" conditions.
2. Convert one or more mixed-flow lanes (coded in the seed file) to HOV lane(s).
   - This option is provided in the methodology to overcome the lack of an HOV lane analysis capability in the HCM 2010 freeway analysis procedure.
   - This option reduces the capacity of the mixed-flow lane(s) to the user specified value for the HOV lane(s). This value is compared to the user specified number of HOVs likely to use the HOV lane(s) and the lower of the two values is the selected capacity for the HOV lane(s). A weighted average capacity across all lanes is then computed to obtain the final capacity adjustment factor used in the scenario. It is assumed that the number of carpools using the HOV lane is exactly the value specified by the user. The HCM 2010 does not provide a procedure to estimate the performance of only the HOV lane. The methodology uses the lower HOV lane capacity to estimate the average capacity across all lanes on the freeway. This accounts for the fact that the mixed-flow lanes may be more congested than the HOV lane, because SOVs are not allowed to use the HOV lane, and some eligible HOVs choose to not use the HOV lane (for various reasons, including needing to exit at the next off-ramp).[4]
3. Open the HOV lane(s) up to all traffic. The HOV lane becomes a mixed-flow lane with the capacities and free-flow speeds typical of the other mixed-flow lanes in the segment.
4. Convert one or more mixed-flow lanes (coded in the seed file) to HOT lane(s) with the capacity per lane identified by the user.
   - This option assumes that the toll will be dynamically set as low as necessary to equalize demand across all lanes until the HOT lane(s) capacity is reached, at which point the HOT lane(s) capacity will control.
5. Open the HOT lane(s) up to all traffic with no toll. The HOT lane(s) become in essence mixed-flow lane(s) with the capacities and free-flow speeds typical of the other mixed-flow lanes in the segment.

Due to limitations of the HCM 2010 freeway analysis procedure, all HOV and HOT lanes must extend the full length of the freeway and must be continuously accessible from the mixed-flow lanes (no barrier separation).

The analytical details for these options are given in Appendix G: Speed/Capacity for HOV/HOT Lane Strategies.

Shoulder and Median Lane Strategies

Seven strategies for temporary use of shoulder and median lanes are available in the ATDM analysis framework (in addition to the "no change" option).

- No change to "before" conditions.
- Shoulder lane temporarily opened up as an auxiliary lane between the on-ramps of the facility and the off-ramps.
- The shoulder lane is opened continuously over the length of the facility to buses only.
- The shoulder lane is opened continuously over the length of the facility to HOVs only.
- The shoulder lane is opened continuously over the length of the facility to all vehicles.

For median lanes, the same options are available as for shoulders, with the exception that median auxiliary lanes is not available as an option. More analytical details on capacities and speeds for these options are provided in Appendix H: Speed/Capacity for Shoulder/Median Lane Strategies.

[4] The average freeway speed computed using the HCM curves and the method's average capacity probably underestimates the speeds in the HOV lane.

Truck Controls

Two options are available for truck controls: "Base" (no change from the seed file), or "Truck Ban," which removes the user specified number of trucks (specified by the user as a percentage of the total traffic stream).

The user-specified PCE value per truck is used along with the percent trucks to compute the capacity adjustment factor for the freeway.

The user specified percent of trucks is used to compute the demand reduction factor (1% trucks) to be applied to all facility demands.

The user should verify that his or her entries for percent trucks and PCEs are consistent with the user's entries in the seed file for percent trucks and general terrain type. Since it is possible for a gross vehicle weight limit to affect less than 100% of the trucks on the freeway with 6 tires, the percent trucks entered by the user for the truck ban can be less than or equal to the total percent trucks on the facility.

A truck ban is assumed to apply to the full length of the freeway for the entire duration of the study period.

Until such time as the HCM 2010 freeway method has a procedure for estimating the effects of trucks on average free-flow speeds, the ATDM analysis procedure assumes that a truck ban would have no effect on facility free-flow speeds.

Ramp Metering

Three ramp meter strategies are provided in the ATDM Analysis methodology, in addition to the "no change" option.

- No change to "before" conditions.
- Meters operating at fixed (potentially varying by time of day) rates during the study period.
- Meters operating in dynamic local optimal mode. Each ramp meter optimizes its own rate based on the freeway mainline volumes immediately upstream and downstream of the ramp.
  - The methodology sets the meter rate for each 15-minute analysis period at each ramp as the difference between the target mainline maximum downstream freeway flow rate and the upstream mainline freeway flow rate for the segment where the ramp is located (subject to the user specified maximum and minimum rates per on-ramp lane).

Additional analytical details are provided in Appendix I: Speed/Capacity for Ramp Metering Strategies.

5.6 Step 6: Convert Strategy into Operations Inputs

In this step the ATDM response plans specified in the previous step are converted into the appropriate traffic operations analysis input parameters.

For scenarios where multiple plans are in effect (for example, an incident in a work zone during bad weather), then (with the exception of the free-flow speed adjustment factor) the effects are multiplied together (assuming independent multiplicative effects). The individual demand or capacity effects for each plan are multiplied to obtain the combined effect of multiple ATDM plan responses.

The exception to this assumption is the free-flow speed adjustment factor. The combined effect is assumed to be the minimum of each of the plan factors. Thus for an incident (with a normal speed adjustment of 0.50) occurring in a work zone (with the work zone speed adjustment being 0.75), the combined effect on free-flow speed is assumed to be the minimum of the two plans, or 0.50, not the two factors multiplied together.

5.7 Step 7: Apply Operations Analysis Tool ("After" Analysis)

This step involves coding the ATDM strategies into each of the operations analysis model input files for the demand/capacity scenarios. For some ATDM strategies, such as time-of-day ramp metering, a single set of adjustments may apply to all of the demand and capacity scenarios. For traffic responsive and incident responsive ATDM strategies the adjustments may vary not only by scenario but also for each time slice within the scenario. The analyst may find it desirable to create a "control emulator" that reads the demands each time slice within each demand and capacity scenario and applies the appropriate capacity and control adjustment, to automate the adjustments. Table 17 shows how this process may be automated for each ATDM strategy.

Table 17: Automated Application of User-Specified ATDM Control Strategy Adjustments

Strategy	By Scenario	By 15-Minute Analysis Period[a]	By Freeway Segment and Ramp[a]
Recurring TDM Plan	Applied By Demand Level	Applied uniformly to all periods	Applied uniformly to all segments
Weather TMP	Applied By Weather Type	Applied only for periods with weather	Applied uniformly to all segments
Traffic Incident (TIM) Plan	Applied By Incident Type	Applied only for periods with incident	Applied only to segments with incident
Work Zone TMP	Applied By Work Zone Type	Applied only for periods with work zones	Applied only to segments with work zones
Variable Speed Limits (VSL)	Applied only to incident and/or work zone scenarios	Applied to periods with incidents or work zones	Applied to segments upstream of work zones or incidents
HOV/HOT	User Specified[b]	Applied uniformly to all periods	Applied uniformly to all segments
Dynamic Shoulder Lane	User Specified[b]	Applied uniformly to all periods	Applied per user specifications
Dynamic Median Lane	User Specified[b]	Applied uniformly to all periods	Applied per user specifications
Truck Controls	User Specified[b]	Applied uniformly to all periods	Applied uniformly to all segments
Ramp Metering	User Specified[b]	Automated if dynamic metering selected	Automated if dynamic metering selected

Note: [a] If user does not agree with automated application approach shown in table, user can post-process the recommended adjustments by analysis period and segment.

[b] User Specified: User must specify scenario to which the control strategy applies.

In cases where the ATDM measure is expected to influence the frequency, severity, or duration of incidents, then the probabilities of the capacity scenarios with incidents will need to be modified as well. A full discussion on developing both "before" and "after" incident probabilities follows. Reductions in incident duration times are dependent on the type of traffic incident management strategy deployed.

Estimating "Before" Probabilities for Incidents

Ideally, the analyst has access to complete incident data logs for a metropolitan area or an extended facility from which the probabilities for each incident level in the experimental design can be developed directly. If this is not possible, a simple method for estimating the probabilities associated with various incident categories pivots off of information on crashes, which are a subset of total incidents. Roughly 15-30% of total incidents are crashes; for the purpose of this report, a value of 20.4% is used, based on data from the SHRP 2-L08 research. Wherever possible incident data logs should be used to develop local values for this factor. The expected number of annual incidents on facility for a particular time period is then:

$$E(inc) = PeriodVMT\ x\ CrashRate\ x\ IncidentProportionFactor$$

The incident proportion factor is the reciprocal of the percent of total incidents that are crashes. Using the default value from SHRP 2-L08, this is 1/0.204 or 4.9. Note that the VMT is computed for the entire year must apply only for the period being studied, e.g., weekday/nonholiday peak period.

If the analyst wishes, the *Highway Safety Manual* can be used to estimate the expected number of annual crashes, which are then factored up to annual incidents using the *Incident Proportion Factor*.

Once the expected number of annual incidents is obtained, it is assumed that no more than one occurs each "day" on the facility. In reality, more than one can occur on a day, but the analytic method is not capable of modeling this situation. However, the total number of annual incidents is preserved by assuming that the number of days with incidents in a year is equal to the total annual incidents. The probability that any kind of incident occurs on the facility over the course of a year is then the expected number of incidents divided by the number of days in a year represented by the analysis period. For example, consider that we have estimated that 90 incidents occur during the AM peak period for weekday/nonholidays. This represents 90/250 = 36%. So, the probability of having an incident–free day is 64%.

The next step is to break out the 36% total incident probability into the levels chosen by the analyst. This is done by using the incident distributions presented earlier, maintaining the relative proportions between categories.

Impacts of Strategies Affecting Incident Frequency (Occurrence)

Several ATDM strategies – as well as traditional safety countermeasures – reduce the frequency of crashes on facilities. A simple method for accounting for the positive effect of some strategies on crashes adjusts the probabilities previously defined for the incident factor in the experimental design. The following example will illustrate the method.

The analyst has already defined the following levels and probabilities for the incident dimension:

- No incident: 70%;
- 1 lane blocked, 30 min.: 20%; and
- 2+ lanes blocked, 30 min.: 10%.

In the above distribution, the probability of an incident is 30%. If the analyst is considering weekday/ nonholidays (250 days per year), then the expected number of total incidents is: 0.30 * 250 = 75. Implementing a safety improvement on the facility is expected to reduce crashes by 18%, based on published crash reduction factors. Assuming that crashes are 20.4% of total incidents, the expected reduction factor for total incidents is: 0.18 * 0.204 = 0.037. Total incidents are then calculated to be: 75 * (1 – 0.037) = 72.2, or 28.9% of weekday/nonholidays. Therefore, the number of days with no incident is: 1 – 0.289 = 0.711. To complete the example, we keep the proportions for the incident categories constant, in this case, 2:1.

- No incident: 71.1%;
- 1 lane blocked, 30 min.: 19.3%; and
- 2+ lanes blocked, 30 min.: 9.6%.

5.8 Step 8: Compute MOEs (“After” Condition)

The “After” MOEs are computed for each demand/capacity scenario using the same procedures as were used for the “before” case.

Adjustments for Congestion Spill Over

In cases where the estimated queues spill over the temporal and/or spatial limits of the operations analysis tool then the best solution is to expand the limits of the tool and rerun the analysis. The limits should be revised if the spillover is frequent, occurring in many scenarios with cumulative probability of greater than 10%.

However, if the cumulative probability of those scenarios with spillovers is less than 10%, then the analyst may consider whether resource constraints, the low probabilities of such extreme scenarios, and cost-effectiveness considerations, may limit the ability to expand the limits. In such situations, it is necessary for the analyst to work with the study stakeholders to:

1. Assess the probability (and therefore the significance) of the scenarios causing the overflow;
2. Assess the degree to which not accurately modeling the overflows will introduce bias that would significantly affect the decisions regarding ATDM investments, and, if significant;
    a. Determine if a reasonable increase in the study limits will adequately capture the overflows, and if not;
    b. Approximately account for the congestion spill over outside of the operations analysis tool limits. Use the methodology described in Step 4.

6 Example Applications

This chapter describes several example applications of the ATDM Analysis method to the estimation of annual facility performance.

The first part of the example application is devoted to establishing the baseline, before ATDM conditions. The example then proceeds to test three ATDM investment strategies: convert an HOV Lane to HOT (with congestion pricing), install dynamic ramp metering, and implement a recurring congestion TDM program with a targeted incident-based TDM program.

The example applications described here do not illustrate the computation of long-term demand effects.

6.1 Before ATDM Analysis

The first phase of an ATDM investment analysis is the "before" ATDM analysis. This phase of the analysis establishes the scenarios against which ATDM will be tested and sets the baseline against which the benefits of ATDM investments will be evaluated.

Step 1 – Preparation

This step involves determining the study purpose, approach, and scope, as well as gathering the data needed for the ATDM analysis.

Establish Purpose and Approach

The selected study freeway currently experiences relatively little recurrent congestion, but it is operating very close to the margin. Work zones, weather, and incidents can have significant effects on congestion. The left most lane is currently dedicated to HOV 2+ during the weekday PM peak periods. The HOV lane is currently slightly underutilized, carrying at most 1,350 vehicles per hour.

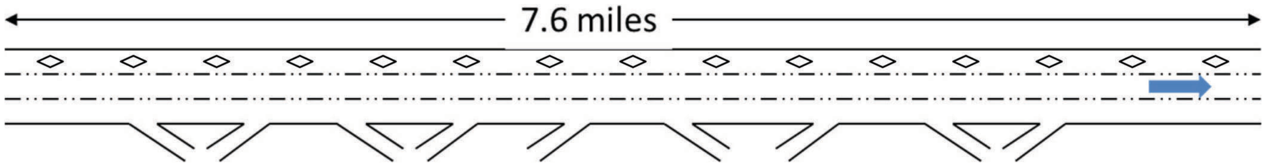
The agency wishes to determine if ATDM strategies might be employed to take advantage of the spare capacity in the HOV lane during weather, work zone, and incident events and thereby better optimize facility productivity.

The purpose of the analysis is to determine which ATDM investments will be cost-effective for addressing nonrecurring congestion on the facility. The approach will be to perform a Highway Capacity Manual (HCM)-based analysis, because at this early investment decision-making stage, it is not necessary to identify specific operating parameters for ATDM, such as the precise ramp metering rates, or the wording of the messages to be delivered as part of an ATDM-driven 511.org traveler information system.

Set Geographic and Temporal Scope

The selected study site is a 7.6-mile-long section of three-lane freeway in one direction with 5 on-ramps and 4 off-ramps, as shown schematically in Figure 9.

Figure 9: Example Application Study Site



Source: Cambridge Systematics, Inc.

The selected study period is the 4-hour weekday PM peak period. The selected reliability reporting period is all weekday PM peak periods within a calendar year, excluding 10 holidays. Thus the reliability reporting period is 250 weekdays of the year.

Data Collection

Data is assembled for the selected study facility and time period for a traditional HCM freeway facility analysis (this HCM data becomes the "seed file" for the reliability analysis and generation of scenarios). Data is then assembled on the day-to-day variability of demand, the historic frequencies of adverse weather, the frequencies of incidents and crashes, and the frequencies of work zones by type.

Seed File Data

The ATDM Analysis method requires that sufficient data for a single day's study period be gathered to code and calibrate the selected core HCM analysis tool. For this example the HCM 2010 FREEVAL-ATDM spreadsheet program was selected as the core analysis tool. Required data is geometry and 15-minute ramp and mainline counts for the 4-hour study period. 16 unique spreadsheets representing each of the analysis periods and containing the geometry and count information for that period, would need to be populated.

Table 18 shows the geometric and demand data for the first 15-minute analysis period within the selected 4-hour study period. The geometry and other parameters (such as percent trucks) are identical in this example for all analysis periods. Although not shown, mainline and ramp demands are assumed to increase 10% in each analysis period following the first analysis period. Starting with the ninth analysis period the mainline and ramp demands decrease 10% from the previous analysis period. Demand is shown in vehicles per hour (vph).

Demand Variability Data

A nearby permanent count station on the facility was queried to obtain the variation in weekday demands over the course of a year. The resulting demands were compared to the seed file demands and the adjustment factors and probabilities were obtained. The results are shown in Table 19.

Weather Data

Weather data for the past 3 years was obtained for a nearby weather station. The data was aggregated into HCM weather types. Probabilities were computed for the weekday PM peak period. Capacity adjustment factors were obtained from the HCM 2010. Free-Flow Speed adjustment factors were obtained from the SHRP 2-L08 research, (Publication of the final report is pending). Demand was assumed to be unaffected by weather for this example problem. The resulting data are shown in Table 20.

Incident Data

Incident data for the past 3 years was obtained from facility incident logs. The log incident types were converted to HCM incident types and the frequencies converted into probabilities. The capacity adjustments were obtained from the HCM 2010. Free-flow speed adjustments were assumed to be equal to the capacity adjustments. Demand was assumed to be unaffected by incidents. The resulting data are shown in Table 21.

Table 18: Input Data for Seed File (Analysis Period #1)

SEGMENT:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Type	B	B	OFR	B	ONR	B	OFR	B	ONR	B	W	B	ONR	B	OFR	B	ONR	B	B	B
Length (ft)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Lanes	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Free-Flow Speed (mph)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Demand (vph)	2,700	2,700	2,700	2,500	2,700	2,700	2,700	2,500	2,700	2,700	2,800	2,600	2,700	2,700	2,700	2,500	2,600	2,600	2,600	2,600
Capacity Adj.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Origin Demand Adj.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Destination Demand Adj.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Speed Adjust.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
% Trucks	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
% RV's	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
On-Ramp Demand (vph)					200				200		100		100				100			
On-Ramp % Trucks					5				5		5		5				5			
On-Ramp % RV's					0				0		0		0				0			
Off-Ramp Demand(vph)			200				200				200				200					
Off-Ramp % Trucks			5				5				5				5					
Off-Ramp % RV's			0				0				0				0					
Acc/Dec Lane Length (ft)			300		300		300		300				300		300		300			
Lanes on Ramp			1		1		1		1		1		1		1		1			
Ramp Side			Right		Right		Right		Right		Right		Right		Right		Right			
Ramp FFS (mph)			45		45		45		45		45		45		45		45			
Ramp Meter Rate (vph)					2,100				2,100		2,100		2,100				2,100			
Ramp-to-Ramp Demand (vph)											32									

Note: Data for Analysis Period #1 shown. Other analysis periods identical, except for volumes. Volumes increase 10% each analysis period between AP #1 and AP #8 (inclusive). Volumes decrease 10% each analysis period between analysis periods #8 and #16.

Table 19: Demand Variability Data for Example Problem

Level of Demand	Ratio of Demand to Seed File Demand	Probability
5th Percentile Highest Demand	0.77	10.0%
15th Percentile Highest Demand	0.93	10.0%
30th Percentile Highest Demand	0.97	20.0%
50th Percentile Highest Demand	1.00	20.0%
70th Percentile Highest Demand	1.02	20.0%
85th Percentile Highest Demand	1.04	10.0%
95th Percentile Highest Demand	1.05	10.0%
Average or Total	0.977	100.0%

Note: The seed file demands are 2.3% higher than the average demands for the year.

Table 20: Weather Probability, Capacity, Speed and Demand Data for Example Problem

Weather	Range	Free-Flow Speed Adj.	Capacity Adjust.	Demand Adjust.	Probability
Clear	N/A	1.00	1.00	1.00	50.0%
Light Rain	>0.00 and <= 0.10 in/hr	0.98	0.98	1.00	8.0%
Medium Rain	>0.10 and <= 0.25 in/hr	0.94	0.93	1.00	4.0%
Heavy Rain	>0.25 in/hr	0.93	0.86	1.00	2.0%
Very Light Snow	>0.00 and <= 0.05 in/hr	0.89	0.96	1.00	6.0%
Light Snow	>0.05 and <= 0.10 in/hr	0.88	0.91	1.00	3.0%
Medium Snow	>0.10 and <= 0.50 in/hr	0.86	0.89	1.00	2.0%
Heavy Snow	>0.50 in/hr	0.85	0.76	1.00	2.0%
Moderate Wind	>10 and <= 20 mph	0.99	0.99	1.00	4.0%
High Wind	>20 mph	0.98	0.98	1.00	2.0%
Cool	<50 and > 34^0 F	0.99	0.99	1.00	2.0%
Cold	<34 and >=-4^0 F	0.98	0.98	1.00	2.0%
Very Cold	<-4^0 F	0.94	0.91	1.00	3.0%
Medium Visibility	<1.00 and >= 0.50 miles	0.94	0.90	1.00	2.0%
Low Visibility	<0.50 and >= 0.25 miles	0.93	0.88	1.00	2.0%
Very Low Visibility	<0.25 miles	0.93	0.88	1.00	6.0%
	Average or Total	0.97	0.97	1.00	100.0%

Table 21: Incident Probability, Capacity, Speed and Demand Data for Example Problem

Incident Type	Max. Lanes Blocked	Free-Flow Speed Adjust.	Capacity Adjust	Demand Adjust	Probability
No Incident Present	N/A	1.00	1.00	1.00	50.0%
Noncrashes	Shoulder	0.99	0.99	1.00	10.0%
	1	0.79	0.79	1.00	7.0%
	2+	0.61	0.61	1.00	6.0%
Property Damage Only Crashes	Shoulder	0.86	0.86	1.00	5.0%
	1	0.79	0.79	1.00	4.0%
	2+	0.61	0.61	1.00	4.0%
Injury Crashes	Shoulder	0.86	0.86	1.00	3.0%
	1	0.79	0.79	1.00	3.0%
	2+	0.61	0.61	1.00	3.0%
Fatal Crashes	Shoulder	0.86	0.86	1.00	1.0%
	1	0.79	0.79	1.00	2.0%
	2+	0.61	0.61	1.00	2.0%
Average or Total:		0.89	0.89	1.00	100.0%

Table 22: Work Zone Probability, Capacity, Speed and Demand Data for Example Problem

Work Zone Type	Lanes Open	Capacity/Lane	Free-Flow Speed Adjust	Demand Adjust	Probability
No Work Zone	All	2,000	1.00	1.00	70.0%
Short-Term	1	1,600	0.80	1.00	5.0%
	2	1,600	0.80	1.00	5.0%
	3	1,600	0.80	1.00	5.0%
Long-Term	1	1,400	0.70	1.00	5.0%
	2	1,450	0.73	1.00	5.0%
	3	1,500	0.75	1.00	5.0%
Average or Total			0.93	1.00	100.0%

Work Zone Data

Work zone types and probabilities for the study section of freeway were obtained by consulting with agency engineers. The capacity adjustments were obtained from the HCM 2010. Free-flow speed adjustments were assumed to be equal to the capacity adjustments. Demand was assumed to be unaffected by incidents. The resulting data are shown in Table 22.

Step 2 – Generate Scenarios

The seven possible levels of demand, the 16 weather types, the 13 incident types, and the 7 work zone types are combined into 10,192 possible scenarios for analysis. The probability of any given scenario is estimated by multiplying together the probabilities of the individual types and demand levels. From these 10,192 possible scenarios, 30 scenarios are selected for detailed analysis of the effectiveness of the proposed ATDM strategies. Since the objective of the ATDM analysis is to estimate the benefits of the different ATDM strategies for a representative cross-section of possible demand, weather, incident, and work zone conditions, a targeted selection of scenarios is selected representing possible combinations of demand weather, incidents, and work zones.

Since the total number of scenarios must be kept to 30 (due to effort involved in designing custom ATDM strategy responses for each scenario), the following sampling scheme is employed for selecting the 30 scenarios:

- Three demand levels (low, medium, high)
- Three weather types (clear, medium rain, light snow)
- Two incident types (no incident, property damage only crash blocking one lane)
- Two work zone types (No work zone, Long-Term maintaining 3 lanes open)

This selection results in 36 possible combinations (3x3x2x2), so some possible combinations will have to be excluded. After considering the relative probabilities and taking into account that the ATDM strategies to be evaluated do not involve snow strategies, the possible combination of property damage only crashes with light snow will not be evaluated.

The final 30 scenarios selected for ATDM analysis are listed in Table 22. Note that the total probability of these particular 30 scenarios is slightly under 9% (see "Initial Probability" column). The HCM analysis results for these 30 scenarios must be weighted to obtain total annual performance over the reliability reporting period for the facility. On the assumption that we have selected an unbiased sample, in light of our objective of evaluating the benefits of ATDM investments, the scenario probabilities will be proportionally increased until they sum to 100%. The final probabilities are shown in the right most column of Table 22.

Step 3 – Apply Operations Analysis Tool (Before)

Once the 30 scenarios have been selected, the next step is to input the scenario-specific demand, free-flow speed, and capacity adjustment factors into the selected HCM analysis tool (in this case, FREEVAL-ATDM). Lane closure data for incidents and work zones is also input. The HCM analysis tool is applied 30 times.

Special Note on Analysis of Freeway Facilities with HOV Lanes

At this point in time, the 2010 HCM does not yet incorporate HOV lane analysis capabilities. The recently completed NCHRP 3-96 research project should address this capability, when it is incorporated into the next update of the 2010 HCM. In the interim, an approximate procedure is used in this example problem to evaluate freeway operations with an HOV lane present.

The HOV lane is assumed to be continuously accessible (thus enabling the standard HCM 2010 freeway analysis procedure to be employed with some modest modifications). The total capacity of the three-lane freeway cross section is the weighted average of the capacity of the HOV lane and the other two mixed-flow lanes. Based on the NCHRP 3-96 research, the capacity of the HOV lane is estimated to be nominally 1,800 vehicles per hour per lane. This capacity is compared to the maximum demand for the HOV lane (in terms of eligible HOVs plus violators) and the lower of the two values is used for the HOV lane in the computation of the mixed average capacity across all three lanes for the freeway.

Step 4 – Compute MOEs (Before ATDM)

The resulting "before" ATDM analysis output is shown in Table 22 for the specific scenarios. A summary of the results is provided in Table 24. The mean PM peak period speed on the facility varies from 16 to 64 mph, depending on the scenario. The average annual speed on the facility for the PM peak period is 43 mph.

The facility is unable to serve all of the VMT demand, but the shortfall is less than one hundredth of 1%.

The Planning Time Index (the 95^{th} percentile travel time index) is 3.92, indicating that travelers on the facility must allow for travel times in excess of 3.9 times their normal free-flow travel time to be 95% confident of arriving on time.

Check for Congestion Spill Over

Approximately 9% of the probability is associated with scenarios with over 80% of the 15-minute analysis periods at LOS F. Approximately 7% of the probability is associated with scenarios with maximum queue lengths in excess of 6 miles (facility length is 7.6 miles). This suggests that there is a chance that queue overflows may occur about 7% to 9% of the time.

The congestion overflow, although mostly for low-probability scenarios may result in an underestimation of the delays for the before condition. This means that the benefits of ATDM may be underestimated when compared to this baseline before condition. A conservative underestimation of the benefits of ATDM may be acceptable, especially if subsequent analysis indicates that the benefits of ATDM are sufficient to support a decision to invest in ATDM. Thus, no correction for congestion spill over (beyond the time limits and geographic limits of the study section) will be applied at this time. If subsequent results are so close that such a correction would be deemed necessary to establish the benefits of the ATDM investments, the preferred approach would be to expand the geographic and temporal limits of the analysis.

Table 23: Thirty Scenarios Selected for HCM Analysis for Example Problem

Number	Demand	Weather	Incident	Work Zones	Initial Probability	Final Probability
1	Low	Clear	No	None	1.7500%	19.48%
2	Low	Clear	No	Lng.Trm 3	0.1250%	1.39%
3	Low	Clear	PDO-1	None	0.1400%	1.56%
4	Low	Clear	PDO-1	Lng.Trm 3	0.0100%	0.11%
5	Low	Med. Rain	No	None	0.1400%	1.56%
6	Low	Med. Rain	No	Lng.Trm 3	0.0100%	0.11%
7	Low	Med. Rain	PDO-1	None	0.0112%	0.12%
8	Low	Med. Rain	PDO-1	Lng.Trm 3	0.0008%	0.01%
9	Low	Lt. Snow	No	None	0.1050%	1.17%
10	Low	Lt. Snow	No	Lng.Trm 3	0.0075%	0.08%
11	Med	Clear	PDO-1	None	0.2800%	3.12%
12	Med	Clear	PDO-1	Lng.Trm 3	0.0200%	0.22%
13	Med	Clear	No	None	3.5000%	38.96%
14	Med	Clear	No	Lng.Trm 3	0.2500%	2.78%
15	Med	Med. Rain	PDO-1	None	0.0224%	0.25%
16	Med	Med. Rain	PDO-1	Lng.Trm 3	0.0016%	0.02%
17	Med	Med. Rain	No	None	0.2800%	3.12%
18	Med	Med. Rain	No	Lng.Trm 3	0.0200%	0.22%
19	Med	Lt. Snow	PDO-1	None	0.0168%	0.19%
20	Med	Lt. Snow	PDO-1	Lng.Trm 3	0.0012%	0.01%
21	High	Clear	No	None	1.7500%	19.48%
22	High	Clear	No	Lng.Trm 3	0.1250%	1.39%
23	High	Clear	PDO-1	None	0.1400%	1.56%
24	High	Clear	PDO-1	Lng.Trm 3	0.0100%	0.11%
25	High	Med. Rain	No	None	0.1400%	1.56%
26	High	Med. Rain	No	Lng.Trm 3	0.0100%	0.11%
27	High	Med. Rain	PDO-1	None	0.0112%	0.12%
28	High	Med. Rain	PDO-1	Lng.Trm 3	0.0008%	0.01%
29	High	Lt. Snow	No	None	0.1050%	1.17%
30	High	Lt. Snow	PDO-1	Lng.Trm 3	0.0006%	0.01%
				Total	8.9841%	100.00%

Note: PDO = property damage only crash

Table 24: Before ATDM Detailed Scenario Results

Scenario Number	Scenario Probability	Type	VMTD Veh-miles (Demand)	VMTV Veh-miles (Volume)	VHD delay (hrs)	VHT – Vehicle-Hrs Traveled	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Q Length (mi)	% 15-mins with LOS=F
1	0.1%		100,002	100,002	140	1,569	0.86	7.6	1.1	63.7	59.8	0.00	0.0%
2	8.6%		100,002	100,002	184	1,613	1.02	8.2	1.1	62.0	55.5	0.38	12.5%
3	1.1%	I	100,002	100,002	143	1,571	0.96	7.6	1.1	63.6	59.8	0.00	0.0%
4	1.1%	I	100,002	100,002	1,207	2,635	3.27	61.5	2.2	37.9	15.0	2.15	62.5%
5	4.3%	W	100,002	100,002	262	1,690	0.93	8.4	1.2	59.2	54.4	0.00	0.0%
6	17.2%	W	100,002	100,002	389	1,818	1.09	10.6	1.2	55.0	43.3	1.08	25.0%
7	8.6%	WI	100,002	100,002	270	1,699	1.03	8.4	1.2	58.9	54.4	0.17	0.0%
8	0.1%	WI	100,002	100,002	2,205	3,634	3.51	68.3	2.9	27.5	14.2	3.41	75.0%
9	5.7%	W	100,002	100,002	374	1,803	0.95	8.9	1.3	55.5	51.0	0.00	0.0%
10	10.2%	W	100,002	100,002	623	2,051	1.12	12.7	1.4	48.8	36.3	1.79	31.3%
11	0.0%	I	107,529	107,529	182	1,718	1.03	7.8	1.1	62.6	58.0	0.19	0.0%
12	8.6%	I	107,529	107,529	2,295	3,831	3.51	68.9	2.8	28.1	14.0	3.64	75.0%
13	5.7%		107,529	107,529	172	1,708	0.93	7.8	1.1	63.0	58.0	0.00	0.0%
14	0.6%		107,529	107,529	313	1,849	1.09	10.2	1.2	58.2	45.1	1.20	25.0%
15	0.4%	WI	107,529	107,529	347	1,883	1.11	9.8	1.2	57.1	48.0	0.47	6.3%
16	0.4%	WI	107,529	107,529	3,833	5,370	3.78	77.0	3.8	20.0	13.2	6.06	87.5%
17	0.7%	W	107,529	107,529	312	1,848	1.00	8.7	1.2	58.2	52.1	0.00	0.0%
18	17.2%	W	107,529	107,529	849	2,385	1.17	15.1	1.5	45.1	30.0	3.19	43.8%
19	0.2%	WI	107,529	107,529	504	2,040	1.13	10.9	1.3	52.7	43.8	0.98	18.8%
20	5.7%	WI	107,529	107,526	4,350	5,886	3.86	79.9	4.2	18.3	12.9	6.06	93.8%
21	0.0%		111,830	111,830	193	1,791	0.97	8.0	1.1	62.4	56.7	0.00	0.0%
22	0.1%		111,830	111,830	570	2,168	1.14	12.8	1.3	51.6	35.9	2.60	37.5%
23	0.0%	I	111,830	111,830	209	1,807	1.07	8.1	1.1	61.9	56.7	0.28	6.3%
24	2.1%	I	111,830	111,830	3,158	4,756	3.65	73.4	3.3	23.5	13.5	5.37	81.3%
25	0.0%	W	111,830	111,830	393	1,991	1.04	9.7	1.2	56.2	46.9	1.28	12.5%
26	0.2%	W	111,830	111,830	1,338	2,935	1.22	19.0	1.7	38.1	23.9	4.72	56.3%
27	0.0%	WI	111,830	111,830	451	2,048	1.15	10.9	1.3	54.6	44.0	1.28	25.0%
28	0.4%	WI	111,830	111,668	4,779	6,374	3.93	81.1	4.4	17.5	12.8	6.06	93.8%
29	0.6%	W	111,830	111,830	546	2,143	1.06	10.7	1.3	52.2	42.4	1.76	18.8%
30	0.0%	WI	111,830	110,887	5,198	6,782	4.02	83.7	4.7	16.3	12.4	6.06	93.8%

Table 25: Before ATDM – Summary Results

Measure of Effectiveness		
Vehicle-Miles Traveled (VMT) Demanded	25,847,488	Vehicle-miles
Vehicle-Miles Traveled (VMT) Served	25,847,198	Vehicle-miles
Vehicle-Hours Traveled (VHT)	603,529	Vehicle-hours
Vehicle-Hours Delay (VHD)	234,285	Vehicle-hours
Average Speed	42.83	Mph
Average Delay	32.63	Seconds/mile
PTI (Planning Time Index – 95^{th}% TTI)	3.92	Unit less

Note: TTI = travel time index, ratio of travel time to free-flow travel time

6.2 Example #1 – Convert HOV to HOT Lane

In this example the first component of an overall ATDM investment plan will be examined, namely congestion pricing.

Step 5 – Design ATDM Strategy

Examination of the "before" results determined that congestion regularly occurs at medium to high demand levels (with or without incidents) and suggests that there might be spare capacity in the HOV that could be used during periods of high congestion or incidents. The maximum HOV demand is 1,350 vph compared to a target capacity of 1,600 vph for a HOT lane. Therefore the first component of the ATDM program that will be evaluated is conversion of the HOV lane to a HOT lane with dynamic congestion responsive tolling.

With dynamic congestion pricing, the assumption is that the toll for the HOT lane will be set as low or as high as necessary to fill the HOT lane to its target operating capacity of 1,600 vph. Allowing for some hysteresis the tolling/demand cycle, it will be assumed that a target maximum volume of 1,500 vph will be achieved.

Step 6 – Convert Strategy into Ops Inputs

At this point in time, the 2010 HCM does not yet incorporate HOT lane analysis capabilities. The recently completed NCHRP 3-96 research project should address this capability, when it is incorporated into the next update of the 2010 HCM. In the interim, an approximate procedure is used in this example problem to evaluate freeway operations with a HOT lane present.

The HOT lane is assumed to be continuously accessible (thus enabling the standard HCM 2010 freeway analysis procedure to be employed with some modest modifications). The total capacity of the three-lane freeway cross section is the weighted average of the capacity of the HOT lane and the other two mixed-flow lanes. The policy operating capacity of the HOT lane is set at 1,600 vehicles per hour per lane. This capacity is discounted to 1,500 vph to allow for some inefficiencies in the toll setting process.

Step 7 –Apply Operations Analysis Tool ("After" Condition)

The scenario-specific capacity adjustment factors for the conversion from HOV to HOT lanes are input into the selected HCM analysis tool (in this case, FREEVAL-ATDM). The HCM analysis tool is reapplied to the original 30 scenarios, but this time with capacity adjustment factors tailored to HOT lane operation rather than HOV lane.

Step 8 – Compute MOEs (Opening Day)

The scenario-specific results are presented in Table 26. The summary MOEs are presented in Table 27.

Converting the HOV lane to HOT lane operation results in a 7% reduction in annual vehicle-hours traveled, a 22% reduction in annual vehicle hours of delay and a 7% increase in mean speed on the facility during the PM peak period. The average delay per mile is reduced 22% and the Planning Time Index is decreased by 16%.

The HOT lane enables the freeway to serve 100% of the VMT demand.

The improvements are greatest where the greatest congestion was present in the before conditions, however; all scenarios see better performance with the HOT lane.

Check for Congestion Spill Over

The maximum reported queues are 6.06 miles, which is less than the 7.6-mile length of the facility. The percent of 15-minute analysis periods with LOS F is 94% or less. The two scenarios with these statistics account for 4 tenths of one percent of the probability covered by the 30 scenarios, so if there are queue overflows in these two scenarios, they are likely to have little effects on the overall results.

Table 26: Scenario-Specific Results – HOT Lane

Scenario Number	Scenario Probability	VMTD Veh-miles (Demand)	VMTV Veh-miles (Volume)	VHD delay (hrs)	VHT	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Q Length (mi)	% 15-mins with LOS=F
1	0.1%	100,002	100,002	132	1,561	0.84	7.5	1.1	64.1	60.6	0.00	0.0%
2	8.6%	100,002	100,002	153	1,582	0.99	7.6	1.1	63.2	59.7	0.00	0.0%
3	1.1%	100,002	100,002	134	1,563	0.92	7.5	1.1	64.0	60.6	0.00	0.0%
4	1.1%	100,002	100,002	895	2,323	2.94	53.4	1.9	43.0	16.0	2.07	56.3%
5	4.3%	100,002	100,002	250	1,678	0.90	8.2	1.2	59.6	55.4	0.00	0.0%
6	17.2%	100,002	100,002	337	1,765	1.06	9.8	1.2	56.6	46.7	0.70	18.8%
7	8.6%	100,002	100,002	252	1,680	0.99	8.2	1.2	59.5	55.4	0.00	0.0%
8	0.1%	100,002	100,002	1,730	3,159	3.16	59.3	2.5	31.7	15.0	2.51	68.8%
9	5.7%	100,002	100,002	361	1,789	0.92	8.7	1.2	55.9	52.0	0.00	0.0%
10	10.2%	100,002	100,002	477	1,906	1.09	10.8	1.3	52.5	42.3	1.02	18.8%
11	0.0%	107,529	107,529	162	1,698	0.99	7.7	1.1	63.3	59.0	0.00	0.0%
12	8.6%	107,529	107,529	1,776	3,312	3.16	59.4	2.4	32.5	14.9	2.63	68.8%
13	5.7%	107,529	107,529	160	1,696	0.90	7.7	1.1	63.4	59.0	0.00	0.0%
14	0.6%	107,529	107,529	256	1,792	1.06	9.4	1.1	60.0	48.8	0.82	18.8%
15	0.4%	107,529	107,529	307	1,843	1.06	8.5	1.2	58.3	53.4	0.25	6.3%
16	0.4%	107,529	107,529	3,123	4,659	3.40	66.3	3.3	23.1	14.0	5.16	81.3%
17	0.7%	107,529	107,529	294	1,830	0.97	8.5	1.2	58.8	53.4	0.00	0.0%
18	17.2%	107,529	107,529	680	2,216	1.14	13.5	1.4	48.5	33.9	2.61	37.5%
19	0.2%	107,529	107,529	429	1,966	1.09	9.2	1.3	54.7	50.3	0.30	6.3%
20	5.7%	107,529	107,529	3,655	5,191	3.47	68.8	3.6	20.7	13.7	5.90	87.5%
21	0.0%	111,830	111,830	179	1,776	0.94	7.8	1.1	63.0	58.0	0.00	0.0%
22	0.1%	111,830	111,830	431	2,029	1.11	11.5	1.2	55.1	40.1	1.91	31.3%
23	0.0%	111,830	111,830	189	1,787	1.03	7.8	1.1	62.6	58.0	0.19	0.0%
24	2.1%	111,830	111,830	2,501	4,099	3.29	63.6	2.8	27.3	14.3	4.14	75.0%
25	0.0%	111,830	111,830	345	1,943	1.01	9.1	1.2	57.6	49.9	0.92	12.5%
26	0.2%	111,830	111,830	967	2,565	1.19	15.9	1.5	43.6	28.5	3.61	43.8%
27	0.0%	111,830	111,830	381	1,979	1.10	9.8	1.2	56.5	48.3	0.92	18.8%
28	0.4%	111,830	111,830	4,132	5,730	3.54	70.7	3.9	19.5	13.5	6.06	87.5%
29	0.6%	111,830	111,830	488	2,085	1.03	9.9	1.3	53.6	46.0	1.19	12.5%
30	0.0%	111,830	111,825	4,631	6,229	3.61	73.0	4.2	18.0	13.2	6.06	93.8%

Table 27: Summary Results – HOT Lane

	Before w. HOV	After w. HOT	Difference	%Difference	
Annual VMT Demanded	25,847,488	25,847,488	0	0.0%	veh-miles
Annual VMT Served	25,847,198	25,847,488	290	0.0%	veh-miles
VHT	603,529	561,258	-42,271	-7.5%	veh-hours traveled
VHD	234,285	192,009	-42,276	-22.0%	veh-hours delay
Average Speed	42.83	46.05	3.23	7.0%	mph
Average Delay	32.63	26.74	-5.89	-22.0%	secs/mile
PTI	3.92	3.36	-0.56	-16.5%	

6.3 Example #2 – Dynamic Ramp Metering

While the HOT lane has relieved recurring congestion for the low and medium demand levels, there is still significant congestion on the facility during incidents, adverse weather, and for high demand days (with or without incidents or bad weather). The next ATDM strategy to test is the addition of dynamic ramp metering to the ATDM strategy of converting the HOV lane to a HOT lane. The dynamic ramp metering would be sensitive to expected and unexpected varying demand and capacity conditions on the freeway.

Step 6 – Convert Strategy into Ops Inputs

Locally optimal dynamic ramp metering is emulated in the HCM analysis tool by comparing the predicted total demand (ramp plus mainline) for the on-ramp merge section to the target maximum desirable flow rate for the freeway (for this example the target is set at 2,100 vehicles per hour per lane). The difference between the target merge section volume and the upstream freeway mainline input volume is the ramp metering rate, subject to certain constraints.

- The maximum ramp metering rate is set at 900 vph/lane.
- The minimum ramp metering rate is set as 240 vph/lane.
- If, during the course of the analysis, the number of vehicles stored on the ramp hits 40, then the meter rate is set to the maximum rate until the queue drops below 40 vehicles.

Unlike for HOT lane analysis where the capacity adjustments applied to the entire study period (for each scenario), the dynamic ramp metering analysis is repeated for each ramp *for each 15-minute* analysis period within each scenario. The computed ramp rates become the ramp capacities input into the HCM analysis tool.

The capacities of the ramp merge sections are increased by 3% to account for the capacity increasing effects of ramp metering. This value must be determined by the user. A value of 3% was chosen here based on recent research.

Examination of the seed file ramp volumes suggested that single-lane metered on-ramps would be inadequate to accommodate the expected ramp demands under medium demand conditions. Consequently it was judged that the ramps would have to be expanded to two metered lanes each, for metering to work on this facility. This assumes that a second metered lane could be added on this specific facility.

Step 7 –Apply Operations Analysis Tool ("After" Condition)

The scenario-specific capacity adjustment factors for the conversion from HOV to HOT lanes and the application of dynamic ramp metering are input into the selected HCM analysis tool (in this case, FREEVAL-ATDM). The HCM analysis tool is reapplied to the original 30 scenarios, but this time with capacity adjustment factors tailored to HOT lane operation and dynamic ramp metering.

Step 8 – Compute MOEs ("After" Condition)

The scenario-specific results are presented in Table 28. The summary MOEs are presented in Table 29.

Table 28: Detailed Scenario Results – HOT + Dynamic Metering

Scenario Number	Scenario Probability	VMTD Veh-miles (Demand)	VMTV Veh-miles (Volume)	VHD delay (hrs)	VHT	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Q Length (mi)	% 15-mins with LOS=F
1	0.1%	100,002	100,002	132	1,561	0.84	7.5	1.1	64.1	60.6	0.00	0.0%
2	8.6%	100,002	100,002	153	1,582	0.96	7.6	1.1	63.2	59.7	0.00	0.0%
3	1.1%	100,002	100,002	134	1,563	0.89	7.5	1.1	64.0	60.6	0.00	0.0%
4	1.1%	100,002	100,002	728	2,156	2.85	51.3	1.8	46.4	16.3	2.05	37.5%
5	4.3%	100,002	100,002	250	1,678	0.90	8.2	1.2	59.6	55.4	0.00	0.0%
6	17.2%	100,002	100,002	306	1,734	1.03	9.1	1.2	57.7	50.2	0.52	12.5%
7	8.6%	100,002	100,002	252	1,680	0.96	8.2	1.2	59.5	55.4	0.00	0.0%
8	0.1%	100,002	100,002	1,389	2,817	3.07	57.0	2.3	35.5	15.3	2.12	62.5%
9	5.7%	100,002	100,002	361	1,789	0.92	8.7	1.2	55.9	52.0	0.00	0.0%
10	10.2%	100,002	100,002	436	1,865	1.05	10.1	1.3	53.6	45.4	0.68	18.8%
11	0.0%	107,529	107,529	162	1,698	0.96	7.7	1.1	63.3	59.0	0.00	0.0%
12	8.6%	107,529	107,529	1,402	2,939	3.07	57.0	2.2	36.6	15.2	2.32	62.5%
13	5.7%	107,529	107,529	160	1,696	0.90	7.7	1.1	63.4	59.0	0.00	0.0%
14	0.6%	107,529	107,529	221	1,757	1.03	8.7	1.1	61.2	52.7	0.58	12.5%
15	0.4%	107,529	107,529	304	1,840	1.03	8.5	1.2	58.4	53.4	0.19	0.0%
16	0.4%	107,529	107,529	2,562	4,098	3.30	63.6	2.9	26.2	14.3	4.17	75.0%
17	0.7%	107,529	107,529	294	1,830	0.97	8.5	1.2	58.8	53.4	0.00	0.0%
18	17.2%	107,529	107,529	545	2,081	1.11	12.1	1.3	51.7	37.9	2.02	31.3%
19	0.2%	107,529	107,529	426	1,962	1.05	9.0	1.3	54.8	50.3	0.24	6.3%
20	5.7%	107,529	107,529	3,048	4,584	3.37	66.0	3.2	23.5	13.9	4.98	81.3%
21	0.0%	111,830	111,830	179	1,776	0.94	7.8	1.1	63.0	58.0	0.00	0.0%
22	0.1%	111,830	111,830	294	1,892	1.07	9.7	1.2	59.1	47.1	1.09	18.8%
23	0.0%	111,830	111,830	181	1,779	1.00	7.8	1.1	62.9	58.0	0.00	0.0%
24	2.1%	111,830	111,830	2,010	3,608	3.19	60.9	2.5	31.0	14.6	3.37	68.8%
25	0.0%	111,830	111,830	345	1,942	1.01	9.1	1.2	57.6	50.0	0.87	12.5%

Table 28: Detailed Scenario Results – HOT + Dynamic Metering (continued)

Scenario Number	Scenario Probability	VMTD Veh-miles (Demand)	VMTV Veh-miles (Volume)	VHD delay (hrs)	VHT	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Q Length (mi)	% 15-mins with LOS=F
26	0.2%	111,830	111,830	777	2,374	1.15	14.1	1.4	47.1	32.3	3.17	37.5%
27	0.0%	111,830	111,830	360	1,957	1.07	9.1	1.2	57.1	50.0	0.87	18.8%
28	0.4%	111,830	111,830	3,490	5,088	3.43	68.0	3.4	22.0	13.7	6.06	87.5%
29	0.6%	111,830	111,830	486	2,083	1.03	9.8	1.3	53.7	46.2	1.14	12.5%
30	0.0%	111,830	111,830	4,023	5,621	3.51	70.3	3.8	19.9	13.4	6.06	87.5%

Table 29: Summary Results – HOT + Dynamic Metering

	HOT	HOT + Meter	Diff	%	
Annual VMT Demanded	25,847,488	25,847,488	0	0.0%	veh-miles
Annual VMT Served	25,847,488	25,847,488	0	0.0%	veh-miles
VHT	561,258	531,814	-29,445	-5.5%	veh-hours
VHD	192,009	162,564	-29,445	-18.1%	veh-hours delay
Average Speed	46.05	48.60	2.55	5.2%	mph
Average Delay	26.74	22.64	-4.10	-18.1%	secs/mile
PTI	3.36	2.99	-0.37	-12.4%	

Adding locally optimal dynamic ramp metering to HOT lane operation results in an additional 5% reduction in annual vehicle-hours traveled, an additional 18% reduction in annual vehicle hours of delay and an additional 5% increase in mean speed on the facility during the PM peak period. The average delay per mile is reduced 18% (compared to the HOT lane alone) and the Planning Time Index is decreased by 12% (compared to the HOT lane alone).

When multiple ATDM strategies are studied, the analyst may want to isolate the effects of individual strategies. The only realistic way is to do this is to run each strategy individually as some of the effects may be masked when multiple strategies are analyzed together.

Check for Congestion Spill Over

Since the chances of congestion spill over were judged to be minor in the previous example, and the current example further reduces congestion on the freeway mainline, congestion spill over is not considered a significant concern in this example.

6.4 Example #3 – Incident TDM

While the combination of a HOT lane with dynamic ramp metering has relieved recurring congestion for the low, medium, and high demand levels, there is still significant congestion on the facility during incidents. The next ATDM strategy to test is the addition of recurring and incident-specific TDM to dynamic ramp metering and the HOT lane. The TDM program will be designed to be most effective for incidents.

Step 6 – Convert Strategy into Ops Inputs

Various TDM strategies are considered for reducing recurring demand. A program of strategies that increase as demand increases is adopted. For example, a special program to contact cooperative major employers in the area is put in place for activation when PM peak period demand levels are expected to be greater than normal. (Such a program might allow early release of employees so that demand in the peak is "smoothed.") Based on an independent assessment of the likely effects on facility demand, it is estimated that this program will reduce freeway demands by 1% for low demand levels, 2% for medium demand levels, and by 4% for high demand levels.

A TDM plan for dealing with incidents is developed that provides basic information for property damage only crashes and noncrash incidents. Major employer participation and information dissemination is ramped up when major injury or fatal accidents occur on the facility. Due to the longer durations of fatal and injury crashes, it is expected that the Incident TDM program will be more effective for those types of crashes than for property damage only crashes or other noncrash incidents. An independent assessment estimates that the incident TDM program will reduce freeway facility demands by 10% for fatal and injury crashes, and by 5% for property damage only and noncrash incidents.

Step 7 –Apply Operations Analysis Tool ("After" Condition)

The scenario-specific demand adjustment factors are input into the selected HCM analysis tool (in this case, FREEVAL-ATDM). The HCM analysis tool is reapplied to the original 30 scenarios, but this time with demand adjustment factors tailored to HOT lane operation and dynamic ramp metering.

Step 8a – Compute MOEs ("After" Condition)

The scenario-specific results are presented in Table 30. The summary MOEs are presented in Table 31.

Adding recurring TDM plus incident-specific TDM to locally optimal dynamic ramp metering and HOT lane operation results in an additional 10% reduction in annual vehicle-hours traveled, an additional 35% reduction in annual vehicle hours of delay and an additional 7% increase in mean speed on the facility during the PM peak period. The average delay per mile is reduced 33% (compared to the HOT lane and metering) and the Planning Time Index is decreased by 18% (compared to the HOT lane and metering without TDM).

Overall VMT demand for the freeway is reduced 2% by the recurring and TDM programs.

Check for Congestion Spill Over

Since the chances of congestion spill over were judged to be minor in the previous example, and the current example further reduces congestion on the freeway mainline, congestion spill over is not considered a significant concern in this example.

Step 8b – Combined Effects of ATDM Investments ("After" Condition)

The combined effects of investing in a HOT lane, dynamic locally optimal ramp metering, a TDM program to address recurring congestion, and an incident-specific supplemental TDM program are shown in Table 32.

The planned ATDM investments are estimated to reduce delay by 48%, increase mean speeds by 23%, and improve reliability by reducing the planning time index for the facility by 35%.

Table 30: Detailed Scenario Results – HOT + Meter + TDM

Scenario Number	Scenario Probability	VMTD Veh-miles (Demand)	VMTV Veh-miles (Volume)	VHD delay (hrs)	VHT	Max D/C	Max Travel Time (min)	Mean TTI	Mean Speed (mph)	Min Speed (mph)	Max Q Length (mi)	% 15-mins with LOS=F
1	0.1%	99,002	99,002	129	1,543	0.83	7.5	1.1	64.2	60.7	0.00	0.0%
2	8.6%	99,002	99,002	150	1,564	0.95	7.6	1.1	63.3	59.9	0.00	0.0%
3	1.1%	98,161	98,161	129	1,531	0.83	7.5	1.1	64.1	60.7	0.00	0.0%
4	1.1%	98,161	98,161	554	1,956	2.52	43.4	1.7	50.2	18.0	1.79	25.0%
5	4.3%	99,002	99,002	244	1,659	0.90	8.2	1.2	59.7	55.6	0.00	0.0%
6	17.2%	99,002	99,002	292	1,706	1.02	8.8	1.2	58.0	51.6	0.44	12.5%
7	8.6%	98,161	98,161	243	1,646	0.90	8.2	1.2	59.6	55.6	0.00	0.0%
8	0.1%	98,161	98,161	916	2,318	2.69	47.8	1.9	42.3	16.9	1.87	56.3%
9	5.7%	99,002	99,002	354	1,769	0.92	8.7	1.2	56.0	52.2	0.00	0.0%
10	10.2%	99,002	99,002	418	1,833	1.04	9.8	1.3	54.0	46.6	0.60	18.8%
11	0.0%	104,483	104,483	151	1,644	0.89	7.6	1.1	63.6	59.5	0.00	0.0%
12	8.6%	104,483	104,483	814	2,307	2.69	47.2	1.8	45.3	17.0	2.00	56.3%
13	5.7%	105,378	105,378	151	1,657	0.89	7.6	1.1	63.6	59.5	0.00	0.0%
14	0.6%	105,378	105,378	196	1,701	1.01	8.3	1.1	62.0	55.5	0.40	12.5%
15	0.4%	104,483	104,483	279	1,772	0.95	8.4	1.2	59.0	54.1	0.00	0.0%
16	0.4%	104,483	104,483	1,696	3,189	2.86	51.9	2.4	32.8	16.0	2.90	68.8%
17	0.7%	105,378	105,378	280	1,786	0.95	8.4	1.2	59.0	54.1	0.00	0.0%
18	17.2%	105,378	105,378	408	1,913	1.09	10.5	1.2	55.1	43.5	1.19	18.8%
19	0.2%	104,483	104,483	396	1,888	0.97	8.9	1.3	55.3	50.8	0.00	0.0%
20	5.7%	104,483	104,483	2,099	3,592	2.92	53.6	2.6	29.1	15.6	3.65	75.0%
21	0.0%	107,357	107,357	159	1,693	0.90	7.7	1.1	63.4	59.0	0.00	0.0%
22	0.1%	107,357	107,357	219	1,752	1.03	8.6	1.1	61.3	53.0	0.57	12.5%
23	0.0%	106,445	106,445	159	1,680	0.90	7.7	1.1	63.4	59.0	0.00	0.0%
24	2.1%	106,445	106,445	998	2,519	2.74	48.4	1.9	42.3	16.7	2.06	56.3%
25	0.0%	107,357	107,357	293	1,826	0.97	8.5	1.2	58.8	53.5	0.00	0.0%
26	0.2%	107,357	107,357	537	2,070	1.11	12.1	1.3	51.9	38.1	1.98	31.3%
27	0.0%	106,445	106,445	291	1,812	0.97	8.5	1.2	58.7	53.5	0.00	0.0%
28	0.4%	106,445	106,445	2,015	3,536	2.92	53.3	2.5	30.1	15.7	3.63	75.0%
29	0.6%	107,357	107,357	413	1,947	0.99	9.0	1.3	55.1	50.3	0.00	0.0%
30	0.0%	106,445	106,445	2,458	3,979	2.97	55.1	2.8	26.8	15.3	4.44	81.3%

Table 31: Summary Results – HOT + Meter + TDM

	HOT + Meter	HOT + Meter + TDM	Difference	%Difference	
Annual VMT Demanded	25,847,488	25,390,134	-457,354	-1.8%	veh-miles
Annual VMT Served	25,847,488	25,390,134	-457,354	-1.8%	veh-miles
VHT	531,814	482,868	-48,945	-10.1%	veh-hours
VHD	162,564	120,152	-42,412	-35.3%	veh-hrs delay
Average Speed	48.60	52.58	3.98	7.6%	mph
Average Delay	22.64	17.04	-5.61	-32.9%	secs/mile
PTI	2.99	2.54	-0.45	-17.7%	

Table 32: Summary Results – Combined Effects ATDM Plan

Measure of Effectiveness	Before ATDM	ATDM Plan	Difference	% Diff
Annual VMT Demanded	25,847,488	25,390,134	-457,354	-1.8%
Annual VMT Served	25,847,198	25,390,134	-457,064	-1.8%
Vehicle-Hours Traveled	603,529	482,868	-120,661	-20.0%
Vehicle-Hours Delay	234,285	120,152	-114,133	-48.7%
Average Speed (mph)	42.8	52.6	9.75	22.8%
Average Delay (secs/mi)	32.6	17.0	-15.59	-47.8%
PTI (Planning Time Index)	3.9	2.5	-1.38	-35.2%

Note: VMT = vehicle-miles traveled

7 Use of Alternative Tools

There will be cases where finer temporal sensitivity to dynamic changes in the system will be required for the reliability analysis than can be provided by the typical 15-minute analysis period used by HCM methods. This may occur when evaluating and designing traffic-responsive signal timing, traffic adaptive control, dynamic ramp metering, dynamic congestion pricing, or strategies affecting the prevalence or duration of incidents with less than 10-minute durations. There may also be scenarios and configurations which the HCM cannot address, such as complex merging and diverging freeway sections.

The ATDM Analysis methodology can work with a wide variety of operations analysis tools ranging from microscopic simulation models, mesoscopic simulation models, traffic control optimization models, and Highway Capacity Manual (HCM)-based macroscopic analysis models. The key is to select an analysis tool with the appropriate geographic scale and sensitivities to ATDM improvements that meets the agency's objectives for the analysis and at the same time has data and calibration requirements within the agency's resource constraints.

For guidance on the selection of the appropriate analysis tool, the analyst should consult the following FHWA guidance documents available at: http://ops.fhwa.dot.gov/trafficanalysistools/:

- Volume I: Traffic Analysis Tools Primer;
- Volume II: Decision Support Methodology for Selecting Traffic Analysis; and
- Volume IX: Work Zone Modeling and Simulation – A Guide for Analysts.

The following documents at the same location provide additional guidance on the appropriate application of the various analysis tools:

- Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software;
- Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling;
- Volume V: Traffic Analysis Toolbox Case Studies – Benefits and Applications;
- Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness;
- Volume VII: Predicting Performance with Traffic Analysis Tools;
- Volume VIII: Work Zone Modeling and Simulation – A Guide for Decision-Makers;
- Volume X: Localized Bottleneck Congestion Analysis Focusing on What Analysis Tools Are Available, Necessary and Productive for Localized Congestion Remediation;
- Volume XI: Weather and Traffic Analysis, Modeling and Simulation; and
- Guide on The Consistent Application of Traffic Analysis Tools and Methods.

For situations when the HCM may not be appropriate it is possible to apply this Guide's conceptual framework for evaluating travel time reliability to alternative analysis tools. The same conceptual approach of generating scenarios, assigning scenario probabilities, evaluating scenario performance, and summarizing the results applies when using alternative analysis tools, such as microsimulation, to estimate reliability effects of operations improvements.

Before embarking on the use of alternative tools for reliability analysis, the analyst should consider the much greater analytical demands imposed by a reliability analysis following this guide's conceptual analysis framework. Thousands of scenarios may need to be analyzed using the alternative tool in addition to the number of replications per scenario required by the tool itself to establish average conditions. Extracting and summarizing the results from numerous applications of the alternative tool may be a significant task.

If a microscopic simulation analysis tool is used, a few of the adaptations of this Guide's conceptual analysis framework that were fit to the HCM's 15-minute Highway Capacity Manual 2010 will no longer be needed. Specifically:

- Scenarios may be defined differently and they may be of longer or shorter duration than those used in HCM analysis.
- Incident start times and durations will no longer need to be rounded to the nearest 15-minute analysis period.
- Weather start times and durations will no longer need to be rounded to the nearest 15-minute analysis period.
- Demand will no longer need to be held constant for the duration of the 15-minute analysis period.
- The peak-hour factors used to identify the peak 15-minute flow rate within the hour would no longer be applied. They would be replaced with the microsimulation model's built-in randomization process.
- This Guide's recommended freeway speed–flow curves for weather events and incidents would be replaced with adjustments to the model's car-following parameters, such as desired free-flow speed, saturation headway, and start-up lost time. Unlike incidents, which the tool's car-following logic can take care of, weather is modeled by adjusting the car-following parameters through weather adjustment factors before running the scenarios. Application guidance and typical factors are provided in the FHWA's Traffic Analysis Toolbox (FHWA).

If a less disaggregate tool is used (e.g., mesoscopic simulation analysis tool, dynamic traffic assignment tool, demand forecasting tool), then many of this Guide's adaptations of the conceptual analysis framework to the HCM may still be appropriate or may need to be further aggregated. The analyst should consult the appropriate tool documentation and determine what further adaptations of the conceptual analysis framework might be required to apply the alternative tool to reliability analysis.

8 Summary

The Methodology for Capacity and Operations Analysis of ATDM (ATDM Analysis method) requires the following inputs in addition to the data that would normally be required for a conventional operations analysis of the facility:

- data on the variability of demand;
- collision records or incident logs; and
- weather data.

The incident log documents the frequency of lane closures due to incidents. The weather data documents the typical frequency of bad weather events for the facility.

Archived demand data for the facility is desirable to produce an accurate profile of demand variability over the course of a year. However, demand profiles can be borrowed from a nearby permanent count station for a similar facility, when archived data is not available.

Archived travel time data for the facility is desirable to better calibrate the predicted variability of facility performance over the course of the year.

The ATDM Analysis method produces the following outputs in addition to the full spectrum of outputs produced by a conventional HCM analysis:

- average annual performance inclusive of incidents, weather, and work zones; and
- expected 80^{th} and 95^{th} percentile worst performance (measures of travel time reliability).

The ATDM Analysis methodology is implemented within the context of a traditional macroscopic Highway Capacity Manual (HCM) analysis. However, the general framework employed in the ATDM Analysis allows the analyst to substitute for the conventional HCM tool any facility operations analysis tool deemed appropriate, including mesoscopic and microscopic simulation tools.

While an analyst with sufficient resources available can use a traditional regional demand model to assess the effects of ATDM strategies on demand, the recommended ATDM Analysis methodology provides a sketch planning approach for estimating these effects when the questions being studied do not warrant such an extensive analytical investment.

The Methodology for Capacity and Operations Analysis of ATDM includes a demand and capacity scenario generation method which enables analysts to estimate the current distribution of travel times for their facility when archived travel time data is not available. This method was found to be superior at predicting the yearlong variation in facility performance compared to taking a nine-day sample of facility travel times.

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Appendix A: Speed/Capacity for Weather

Two sources were used to obtain default capacity and free-flow speed adjustment factors for weather that are applicable to freeways. Exhibit 10-15 of the 2010 Highway Capacity Manual (shown in Table 33) provides capacity reductions. Exhibit 36-25 of the SHRP 2-L08 Final Report Draft HCM Chapters (shown in Table 34) provides both capacity and free-flow speed adjustments. Note that 1.00 minus the percent reduction equals the adjustment factor.

The HCM provides capacity adjustments for a slightly greater range of weather conditions than SHRP 2-L08 (Table 34), however; the added weather conditions tend to be ones with marginal effects on freeway capacity. The SHRP 2-L08 capacity adjustments are sensitive to free-flow speed (under fair weather), while the HCM adjustments are not. The SHRP 2-L08 exhibit also provides freeway free-flow speed adjustments for weather.

The HCM capacity reductions and the SHRP 2-L08 capacity adjustments generally match for freeways with 65 mph free-flow speeds. Consequently, the HCM capacity reductions (after conversion to the equivalent capacity adjustment factors) were used in combination with the SHRP 2-L08 free-flow speed adjustments (selected for 65 mph free-flow speed) for the example problem. Where the SHRP 2-L08 speed adjustments were lacking, interpolations of extrapolations of the factors were used. The final selected adjustments for the ATDM example problem are shown in Table 36.

Table 33: HCM Freeway Capacity Reductions for Weather

Type of Condition	Intensity of Condition	Average % Reduction	Range of % Reductions
Rain	>0 ≤ 0.10 in./h	2.01	1.17–3.43
	>0.10 ≤ 0.25 in./h	7.24	5.67–10.10
	>0.25 in./h	14.13	10.72–17.67
Snow	>0 ≤ 0.05 in./h	4.29	3.44–5.51
	>0.05 ≤ 0.10 in./h	8.66	5.48–11.53
	>0.10 ≤ 0.50 in./h	11.04	7.45–13.35
	>0.50 in./h	22.43	19.53–27.82
Temperature	<50^{0}F ≥ 34^{0}F	1.07	1.06–1.08
	<34^{0}F ≥ –4^{0}F	1.50	1.48–1.52
	<–4^{0}F	8.45	6.62–10.27
Wind	>10 ≤ 20 mi/h	1.07	0.73–1.41
	>20 mi/h	1.47	0.74–2.19
Visibility	<1 ≥ 0.50 mi	9.67	One site
	<0.50 ≤ 0.25 mi	11.67	One site
	<0.25 mi	10.49	One site

Source: Exhibit 10-15, 2010 Highway Capacity Manual. Entries are percent reduction in capacity.

Table 34: SHRP 2-L08 Freeway Capacity and Speed Adjustments for Weather

	Capacity Adjustment Factors					Speed Adjustment Factors				
Weather Type	55 mi/h	60 mi/h	65 mi/h	70 mi/h	75 mi/h	55 mi/h	60 mi/h	65 mi/h	70 mi/h	75 mi/h
Medium rain	0.94	0.93	0.92	0.91	0.90	0.96	0.95	0.94	0.93	0.93
Heavy rain	0.89	0.88	0.86	0.84	0.82	0.94	0.93	0.93	0.92	0.91
Light snow	0.97	0.96	0.96	0.95	0.95	0.94	0.92	0.89	0.87	0.84
Light-medium snow	0.95	0.94	0.92	0.90	0.88	0.92	0.90	0.88	0.86	0.83
Medium-heavy snow	0.93	0.91	0.90	0.88	0.87	0.90	0.88	0.86	0.84	0.82
Heavy snow	0.80	0.78	0.76	0.74	0.72	0.88	0.86	0.85	0.83	0.81
Severe cold	0.93	0.92	0.92	0.91	0.90	0.95	0.95	0.94	0.93	0.92
Low visibility	0.90	0.90	0.90	0.90	0.90	0.96	0.95	0.94	0.94	0.93
Very low visibility	0.88	0.88	0.88	0.88	0.88	0.95	0.94	0.93	0.92	0.91
Minimal visibility	0.90	0.90	0.90	0.90	0.90	0.95	0.94	0.93	0.92	0.91
Nonsevere weather	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: Speeds given in column heads are free-flow speeds. Entries are adjustment factors, not percent reductions

With SHRP 2-L08 weather types as defined in Table 34.

Table 35: SHRP 2-L08 Weather Type Definitions for Freeways

Weather Event	Definition
Medium rain	>0.10 ≤ 0.25 in./h
Heavy rain	>0.25 in./h
Light snow	>0 ≤ 0.05 in./h
Light-medium snow	>0.05 ≤ 0.10 in./h
Medium-heavy snow	>0.10 ≤ 0.50 in./h
Heavy snow	>0.50 in./h
Severe cold	<–4˚F
Low visibility	<1 ≥ 0.50 mi
Very low visibility	<0.50 ≤ 0.25 mi
Minimal visibility	<0.25 mi
Nonsevere weather	All other conditions not listed above

Table 36: Selected Weather Adjustments for ATDM Example Problem

Weather Type	Range			Speed Adjustment Factor	Capacity Adjustment Factor	Probability
Clear				1.00	1.00	50.0%
Light Rain	> 0.00	<= 0.10	in/hr	0.98	0.98	8.0%
Medium Rain	> 0.10	<= 0.25	in/hr	0.94	0.93	4.0%
Heavy Rain	> 0.25		in/hr	0.93	0.86	2.0%
Very Light Snow	> 0.00	<= 0.05	in/hr	0.89	0.96	6.0%
Light Snow	> 0.05	<= 0.10	in/hr	0.88	0.91	3.0%
Medium Snow	> 0.10	<= 0.50	in/hr	0.86	0.89	2.0%
Heavy Snow	> 0.50		in/hr	0.85	0.76	2.0%
Low Wind	> 10.00	<= 20.00	mph	0.99	0.99	4.0%
High Wind	> 20.00		mph	0.98	0.98	2.0%
Cool	< 50.00	>= 34.00	degrees F	0.99	0.99	2.0%
Cold	< 34.00	>= -4.00	degrees F	0.98	0.98	2.0%
Very Cold	< -4.00		degrees F	0.94	0.91	3.0%
Medium Visibility	< 1.00	>= 0.50	miles	0.94	0.90	2.0%
Low Visibility	< 0.50	>= 0.25	miles	0.93	0.88	2.0%
Very Low Visibility	< 0.25		miles	0.93	0.88	6.0%
Total						100.0%

Source: 2010 Highway Capacity Manual (Transportation Research Board, 2010) and SHRP 2-L08 Final Report (Vandehey, Ryus, Bonneson, Rouphail, Margiotta, & Dowling, 2013)

Appendix B: Incident Probabilities and Duration

Incident probabilities and durations may be needed for an "existing conditions evaluation" in which case the analyst can take advantage of recent historical experience on the facility. If some of the required data is lacking, this Appendix provides methods to estimate incident probabilities.

For future conditions evaluations, where the facility design is significantly changed, historic crash and incident experience may not provide a sufficient basis for forecasting future incident probabilities. The procedures and defaults in this Appendix may be useful for forecasting future incident probabilities.

For an existing facility evaluation, data-rich agencies will have to convert their incident log data to a compatible format for input in the ATDM analysis procedures. Data-poor agencies typically lack local incident data, but may have access to local crash data, which is identified as one of the common incident types. These agencies will have to populate incident frequency based on crash data. A procedure to estimate incidents from crash data is provided in Section 5.7.For planned or future conditions, both data-rich and data-poor agencies will have to perform extra steps in order to estimate incident frequency. When sufficient traffic and geometry information is available, crash frequency for arterials can be estimated using the crash prediction procedures available in the Highway Safety Manual (HSM) (Highway Safety Manual, 2011). Alternatively, in a situation where only planning-level parameters– such as traffic forecast and length of facilities – are known, incident frequency for either urban freeways or arterials can be estimated using HERS (Highway Economic Requirements System - State Version: Technical Report, 2005) or other crash prediction methodologies. Details for each step and suggested default values for both evaluation types are also provided later in this guideline.

Unfortunately, there is no consistency across agencies' incident data recording systems. Some agencies simply record the incident duration and number of lane closures, without regard to the roadway shoulder. However, the HCM freeway incident classification categorizes shoulder accident, shoulder disablement, and lane closures separately. Most of the incident databases show that shoulder closures are more frequent than lane closures. Consequently, shoulder closures should represent a significant share in the incident type distribution.

The following procedures are recommended for both data-rich and data-poor agencies to prepare and process their incident data or estimate incidents in a compatible format for use in the ATDM analysis.

Estimate Incident Probabilities for the Study Period

Three approaches are described here for estimating incident probabilities. The best approach uses archived incident data for the facility to estimate incident probabilities by incident type. The "Second Best" approach uses historic facility crash rates to estimate incidents. The "Third Best" approach (which must be used if sufficient facility design changes are expected to change crash rates) uses Highway Safety Manual procedures or "rule of thumb" rates from national sources to estimate facility crash rates and then incident probabilities.

Best Approach: Employing Local Incident Data

This option is for agencies with archived incident logs for the facility. The following steps are performed.

1. All incidents occurring within the study limits and the reliability reporting period are extracted from the agency's incident logs for the facility.
   a) Preferably 5 years of data is available to provide a robust estimate of incident probabilities for the facility, but one year of data is acceptable.

2. The incident types in the logs are converted by the analyst into ATDM incident types:
   a) Breakdown, property damage only (PDO), injury, fatal; and
   b) Further subdivided by maximum lanes closed (shoulder, 1, or 2+).
3. The number of incidents (for each incident type) is divided by the number of study periods within the reliability reporting period to obtain the incident probability by type.
   a) For example, if a one year reporting period is covered in the incident data base, and the desired study period is all weekday PM peak periods of the year, then the number of study periods covered by the incident data base is 260 weekday peak periods per year.
      – If 13 shoulder breakdowns were recorded during weekday PM peak periods in the past year, then the probability of that incident type occurring sometime during the weekday PM peak period in the future is 13/260 = 5%.

Second Best Approach: Incident Prediction Based on Local Crash Data

This approach is appropriate for facilities where incident logs are not routinely prepared, are inadequately detailed, or where the incident logs are not accessible to the analyst. It requires that facility-specific crash data be available, preferably over a 3- to 5-year period (with 1 year acceptable).

This approach expands the reported crashes to total incidents using an expansion factor obtained from the SHRP 2-L08 research. The probabilities of incidents by severity and lane blockage type are computed using the following formula.

$$P(inc, sev, block) = P(inc) * P(sev) * P(block)$$

Equation 5

Where:

P(inc, sev, block) = Probability of incident, with severity type “sev,” and lane blockage type “block.”

P(sev) = Probability of incident being one of following severity types: fatal, injury, property damage only, noncrash incident.

P(inc) = Probability of incident occurring on facility within the daily study period. This is equal to 1 – probability of no incidents within the study period. Assuming Poisson distribution of incidents for study period, probability of no incidents = exp(-lambda), where lambda is the average number of incidents per study period

P(block) = Probability of incident being one of following lane blockage types: shoulders only, one lane, two or more lanes.

Substituting the Poisson probability of zero incidents within the study period, we obtain:

$$P(inc, sev.block) = (1 - exp(-\lambda)) * P(sev) * P(block)$$

Equation 6

Where:

Lambda = the average number of incidents per daily study period.

The following steps are used to apply this approach to estimate incident probabilities by severity and blockage type.

1. Estimate annual crashes occurring within the reliability reporting period for the year.

- Assume that crashes are proportional to the volume on the facility.
- Multiply total crashes per year by percent of AADT occurring during the study period.
- For example if the peak hour is typically 10% of average daily traffic on the facility, then assume that 10% of the annual crashes on the facility occur during the peak hour.

2. Estimate the average crashes per daily study period

- Divide the annual crashes in the reliability reporting period by the number of days in the reliability reporting period.
- For example, if the reliability reporting period is the PM peak hour for every weekday of the year, there will be 260 days within the reliability reporting period (52 weeks times 5 days per week).
  - If the facility has 520 crashes per year with 10% occurring during the weekday PM peak hour, then there are on average 520 * 10%/260 = 0.20 crashes per daily study period.

3. Expand crashes per daily study period to total incidents (crashes plus noncrash incidents) per daily study period.

- Use SHRP 2-L08 expansion factor for freeways of 4.9 to expand crashes to incidents.
- Continuing the previous example: 0.20 crashes per daily study period times 4.9 = 0.98 incidents per daily study period.

4. Compute probability of NO incidents occurring during a daily study period.

- Assume incidents occur independently of the time since the last event, making their probability of occurring within the study period a Poisson distribution with a mean equal to the average number of incidents per daily study period.
- Compute the probability of zero incidents within the study period using a Poisson distribution with a mean equal to the average number of incidents per daily study period.
  - Continuing the example, If the mean number of incidents per study period is 0.98, then the probability of no incidents occurring is 37.5%.

5. Allocate Total Incidents by severity.

- The proportions of Noncrash incidents, property damage only (PDO), injury, and fatal crashes can be obtained from Table 37.
- If facility-specific data on crash proportions is available, those proportions should be used instead. The facility-specific proportions will need to be adjusted to account for noncrash incidents so as to ensure that crash plus noncrash proportions add up to one.

6. Allocate Crashes and Noncrashes by lane closures using the proportions for freeways for freeways estimated from incident data tabulated for various U.S. freeways in Table 38.

Table 37: Default Proportions for Incident Severity

Noncrash Incident	Property Damage Only (PDO)	Injury Crash	Fatal Crash	Total
83.05%	14.04%	2.85%	0.06%	100.0%

Source: The ratio of total incidents to crashes used in this table is 4.9, taken from SHRP 2-L08 Final Report. The crashes are proportioned between PDO, injury, and fatal based on national statistics reported in Chapter 2, Table 24 of FHWA Traffic Safety Facts (FHWA, 2010).

Table 38: Default Proportions for Incident Lane Blockage

Incident Type	Blocking Shoulder	Blocking One Lane	Blocking 2 or More Lanes	Total
Crashes (PDO, Injury, Fatal)	55.8%	27.8%	16.4%	100.0%
Noncrash Incidents	83.7%	14.8%	1.6%	100.0%

Source: Freeway incident data in SHRP 2-L08 Final Report (Vandehey, Ryus, Bonneson, Rouphail, Margiotta, & Dowling, 2013).

Estimate Average Incident Duration

For capacity analysis purposes it is necessary to know the incident duration and the number of lanes blocked. The best source of incident durations for a facility is the incident log for the facility, however; the analyst must understand how the time entries in the log are determined to ensure that full incident durations are tallied. Table 39 may be used if superior local data on incident durations is not available.

Table 39: Incident Duration by Crash Severity Type

Severity	Shoulder	One lane	Two+ Lanes	All
Noncrash	29.8	29.1	47.4	30.0
PDO	38.1	42.3	56.9	44.5
Injury	57.4	43.9	46.8	47.6
Fatal	229.6	175.5	187.1	190.2

Note: Entries are average duration in minutes. Adapted from SHRP 2-L08 Final Report White Paper on Incidents. When available, local, facility-specific incident durations should be used in lieu of this table.

Prediction of Facility Crashes

In the absence of facility crash records for a sufficiently long historic period to establish expected crash rates, and in the case when forecasting crashes for a new or upgraded facility the Highway Safety Manual methods may be used to estimate crash rates. The analyst should consult the HSM for details.

Appendix C: Speed/Capacity for Incidents

There are two comprehensive sources of information on the effects of incidents on freeway free-flow speeds and capacities: The 2010 Highway Capacity Manual, and the SHRP 2-L08 Final Report. The HCM 2010 capacity adjustments for incidents (in terms of the proportion of original freeway capacity remaining while the incident is present) are given in Table 40. The SHRP 2-L08 project converted the HCM 2010 adjustments into adjustments to be applied to the remaining lanes open during the incident. In addition the adjustments were extrapolated to four-lanes blocked. The SHRP 2-L08 capacity adjustments are shown in Table 41.

Table 40: Residual Freeway Capacity in Incident Zones per the HCM

Number of Lanes (One Direction) Before Incident	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	0.95	0.81	0.35	0	N/A
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.4	0.2
6	0.99	0.89	0.71	0.5	0.26
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Note: Entries are proportion of original freeway capacity. Source: Exhibit 10-17, 2010 HCM

Table 41: Capacity Adjustment Factors for Incident Zones per SHRP 2-L08

Number of Lanes (One Direction) Before Incident	No Incident	Shoulder Closed	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked	Four Lanes Blocked
2	1.00	0.81	0.70	N/A	N/A	N/A
3	1.00	0.83	0.74	0.51	N/A	N/A
4	1.00	0.85	0.77	0.50	0.52	N/A
5	1.00	0.87	0.81	0.67	0.50	0.50
6	1.00	0.89	0.85	0.75	0.52	0.52
7	1.00	0.91	0.88	0.80	0.63	0.63
8	1.00	0.93	0.89	0.84	0.66	0.66

Note: Entries are capacity adjustments to lanes remaining open during incident. N/A = Not Applicable.
Source: Exhibit 36-16, Draft Chapter for HCM, SHRP 2-L08

Freeway Free-Flow Speed Adjustments for Incidents

Neither source (HCM nor SHRP 2-L08) identifies free-flow speed effects of incidents. The analyst might consider a free-flow speed reduction in the incident section to account for "rubber necking" by drivers distracted by the incident.

Appendix D: Speed/Capacity for Work Zones

The 2010 Highway Capacity Manual and SHRP 2-L08 provide recommended capacity adjustments for freeway work zones. More recent and comprehensive information on the traffic analysis of work zones can be found in Traffic Analysis Toolbox Volume XII (Zhang, Morallos, Jeannotte, & Strasser, 2012). The National Cooperative Highway Research Project (NCHRP) 3-107 will produce additional guidance on the capacity and traffic speeds in work zones in late 2014.

2010 HCM Capacity Adjustments for Freeway Work Zones

Work zones include short-term work zone lane closures due to maintenance and long-term lane closures due to construction. According to the Manual on Uniform Traffic Control Devices (MUTCD), construction duration for long-term work zone is more than three days and could last several weeks, months, or even years, depending on the nature of works. Short-term work zone duration is more than an hour and within a single daylight period (MUTCD, 2009). Long-term construction zones generally use portable concrete barriers, while short-term work zones use standard channelizing devices.

Chapter 10 of the 2010 Highway Capacity Manual (HCM) summarized the lane closures and ranges of capacity during construction (HCM 2010). Exhibit 10-14 of the 2010 HCM provides work zone capacities in terms of vehicles per hour per lane according to the original number of lanes (before work zone) and the number of lanes open when the work zone is in place (Table 42).

Table 42: Capacities of Freeway Work Zones

	1 Lane Work Zone	2 Lanes Work Zone	3 Lanes Work Zone	4 Lanes Work Zone
1 Lane Before				
2 Lanes Before	1,400			
3 Lanes Before	1,450	1,450		
4 Lanes Before	1,350	1,450	1,500	
Range	950-2,000	1,300-2,100	1,300-1,600	
Average Veh/hr/ln	1,400	1,450	1,500	
Pc/hr/ln	1,590	1,650	1,710	

Source: Default values and ranges from Exhibit 10-14 2010 HCM; values shown are vehicles per hour per lane unless otherwise noted.

Note: Pc/hr/ln (passenger cars per hour per lane) equivalent computed assuming level terrain, 5% heavy vehicles, and 0.90 PHF

The vehicle per hour per lane capacities (veh/hr/ln) in Exhibit 10-14 of the HCM were converted to passenger car equivalents for the purpose of computing capacity adjustment factors for work zones. The capacity adjustment factors for a 65 mph free-flow speed freeway are computed assuming that the values in Exhibit 10-14 of the HCM apply to 65 mph free-flow speed freeway with a base (dry weather, nonwork zone capacity of 2,300 pc/hr/ln. The same capacity adjustment factors computed for a 65 mph free-flow speed freeway are assumed to apply to freeways with higher and lower free-flow speeds. In other words, the effect of the work zone on capacity is assumed to be proportional to the base capacity. The resulting capacity adjustment factors applicable to all freeways, regardless of free-flow speed are shown in Table 43. We have extrapolated Exhibit 10-14 of the 2010 HCM to freeway work zones with 5 moving lanes.

Table 43: Capacity Adjustment Factors For Work Zones

Number of Lanes Open in Work Zone	Work Zone Capacity Adjustment Factor
1	0.68
2	0.70
3	0.72
4	0.74
5	0.77

Note: Work Zone Capacity = (Base Capacity) * (Capacity Adjustment Factor).

SHRP 2-L08 Capacity Adjustments for Freeway Work Zones

The SHRP 2-L08 recommends the capacity adjustment factors shown in Table 44. These factors are computed for an assumed 55 mph free-flow speed within the work zone and a base capacity of 2,250 pc/hr/ln.

Table 44: SHRP 2-L08 Work Zone Capacity Adjustment Factors

Directional Lanes (One Direction, Before Work Zone)	1 Lane Closed	2 Lanes Closed	3 Lanes Closed
2	0.62	N/A	N/A
3	0.64	0.64	N/A
4	0.67	0.64	0.60

Note: N/A = Not Applicable, Source: Exhibit 36-17, Draft HCM Chapter, SHRP 2-L08.

Free-Flow Speed Adjustments for Freeway Work Zones

Neither source, HCM 2010 or SHRP 2-L08, identify free-flow speed adjustment factors to apply in work zones. The analyst may consider reductions to account for the lower posted speed limits in freeway work zones, rubbernecking due to driver distractions (and entering and exiting construction vehicles) associated with work zones.

Appendix E: Measures of Effectiveness

This Appendix provides details on the computations of the annual facility performance measures for evaluating ATDM investments. Note that throughout this Guide, the terms "measures of effectiveness" and "performance measures" have been used interchangeably.

Computation of Annual VMT

There are two measures of vehicle-miles traveled (VMT) that are evaluated. The demand VMT is the input demand to the traffic operations tool. The VMT served is the amount of the demand that the traffic operations tool predicts can be served by the facility within the selected study period. These two values of VMT are accumulated for the year by multiplying the VMT input and output by the tool for each scenario by the number of days per year represented by the scenario. The number of days represented by the scenario is determined by multiplying its probability of occurrence by the total number of days in the reliability space being evaluated.

$$AVMT = N * \sum_{s} VMT(s) * P(s)$$

Equation 7

Where:

AVMT = Annual total vehicle miles traveled

N = Number of days within the reliability analysis space.

VMT(s) = VMT estimate for scenario "s."

P(s) = Probability of scenario "s."

The difference between the input demand VMT and the served VMT predicted by the traffic operations analysis tool is the "unserved VMT demand" for the facility.

Computation of Annual VHT

In cases where the estimated queues spill over the temporal and/or spatial limits of the operations analysis tool then the best solution is to expand the limits of the tool and rerun the analysis. The limits should be revised if the spillover is frequent, occurring in many scenarios with cumulative probability of greater than 10%.

However, if the cumulative probability of those scenarios with spillovers is less than 10%, then the analyst may consider whether resource constraints, the low probabilities of such extreme scenarios, and cost-effectiveness considerations, may limit the ability to expand the limits. In such situations, it is necessary for the analyst to work with the study stakeholders to:

1. Assess the probability (and therefore the significance) of the scenarios causing the overflow,
2. Assess the degree to which not accurately modeling the overflows will introduce bias that would significantly affect the decisions regarding ATDM investments, and, if significant,
    a. Determine if a reasonable increase in the study limits will adequately capture the overflows, and if not,
    b. Approximately account for the congestion spill over outside of the operations analysis tool limits as described below.

The annual vehicle hours traveled (VHT) should include delays to vehicles waiting (or denied entry) to the facility during the study period, plus the time spent traveling or stopped within the facility. The reported VHT may also need to be adjusted for residual queues remaining within the facility or at its entry segments according to the following equation.

$$VHT'(s) = VHT(s) + \frac{DAP}{60} * \sum_{a} VDE(a,s) + \sum_{j} \frac{Q(j,s)^2}{2c(j)}$$

Equation 8

Where:

VHT'(s) = Adjusted vehicle-hours traveled for scenario "s" (veh-hrs).

VHT(s) = Vehicle hours traveled reported by analysis tool for scenario "s" (veh-hrs).

DAP = Duration of analysis period, for HCM it is typically 15 minutes (min).

VDE(a) = Number of vehicles denied entry to facility at end of analysis period "a" (veh).

Q(j,s) = Number of vehicles remaining in queue on entry segments "j" at end of last analysis period for scenario "s" (veh).

c(j) = Capacity of facility entry segment "j" (veh/hr).

These adjustments are explained below.

Adjustment for Vehicles Denied Entry (does not apply to all analysis tools): Some operations analysis tools do not accumulate and report the delay for vehicles denied entry to the facility. In such cases the analyst will need to manually accumulate the delays to these vehicles for each analysis period and add them to the VHT reported by the traffic operations analysis tool for the scenario (see second term in Equation 8).

Adjustments for Temporal Spill Over of Queues (Queues remaining at end of last analysis period): In cases where the queuing persists through the last analysis period, the analyst should manually compute the time necessary to clear the queue remaining at the end of the last analysis period assuming no new demand arrives. This added time is divided by two (to get the average delay per vehicle) and multiplied by the number of vehicles in the queue to obtain the residual delay (see third term in Equation 8).

The capacity for each entry segment with a residual queue (see third term in Equation 8) will be the discharge rate for that segment during the last analysis period within the study period.

Computation of Annual VHD

The annual vehicle hours of delay (VHD) are computed by subtracting the estimated vehicle-hours traveled if all travel demand were at free-flow speed from the adjusted VHT.

Computation of Annual Delay per VMT

The annual average delay (in seconds) per vehicle-mile traveled (VMT) is computed by dividing the annual VHD by the Annual Demand VMT and multiplying the result by 3,600 seconds per hour. If average delay per trip is desired, the annual delay per VMT is divided by the average trip length on the facility. If the majority of trips on the facility are through trips (traveling end to end on the facility), then the average trip length will be somewhat less than the length of the facility.

Computation of Annual Average Speed

The annual average speed for the facility is the VMT demand divided by the adjusted VHT.

Computation of Reliability Statistic

The mean travel time indices (TTI) for each scenario are sorted from lowest to highest and the probabilities of each scenario accumulated to obtain the cumulative percentiles. The analyst then interpolates from the table the desired percentile TTI results. The 95^{th} percentile TTI is the Planning Time Index. In the example shown in Table 45, the Planning Time Index is approximately 1.69. A similar procedure is used to compute the 80^{th} Percentile TTI as 1.238.

Table 45: Example Computation of PTI

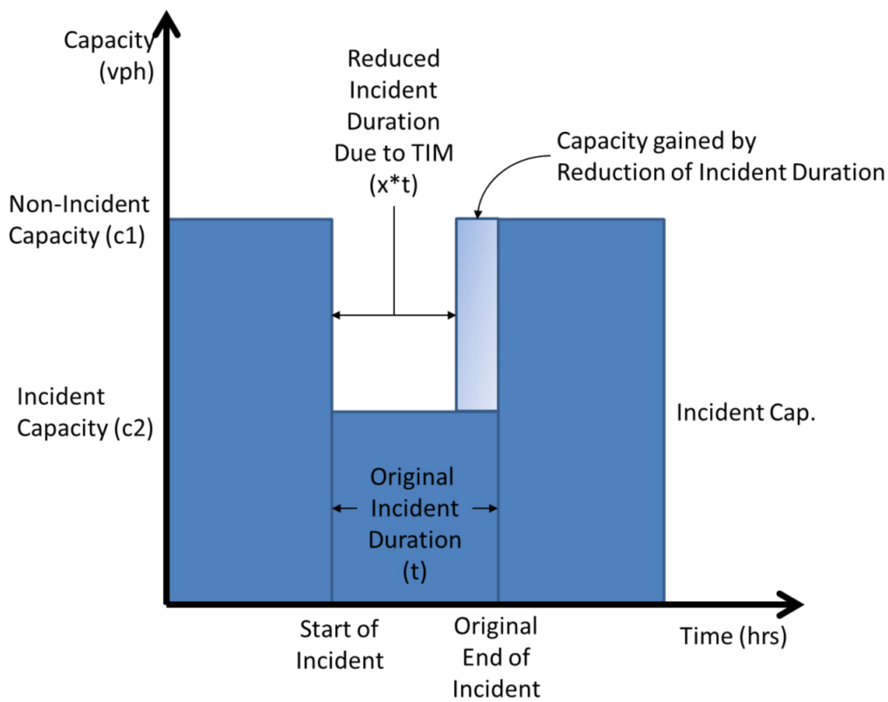
Sorted Mean TTI for each scenario	Scenario Probability	Cumulative Probability
1.058	0.06%	0.06%
1.060	1.14%	1.20%
1.060	5.72%	6.92%
1.061	0.02%	6.95%
1.062	0.00%	6.95%
1.063	0.01%	6.96%
1.073	8.58%	15.54%
1.075	0.57%	16.11%
1.076	0.11%	16.22%
1.149	4.29%	20.51%
1.150	8.58%	29.09%
1.164	17.16%	46.25%
1.170	0.69%	46.94%
1.171	0.41%	47.34%
1.185	17.16%	64.50%
1.196	0.03%	64.54%
1.197	0.01%	64.54%
1.211	0.23%	64.77%
1.224	5.72%	70.49%
1.239	10.21%	80.71%
1.257	0.20%	80.91%
1.281	0.61%	81.52%
1.354	1.14%	82.67%
1.420	8.58%	91.25%
1.462	2.06%	93.30%
1.505	0.12%	93.43%
1.604	0.41%	93.84%
1.682	0.41%	94.24%
1.715	5.72%	99.96%
1.796	0.04%	100.00%

Note: $95^{th}\% = (0.9500-0.9424)/(0.9996-0.9424) * (1.715-1.682) + 1.682 = 1.686$

Appendix F: Speed/Capacity for Incident Duration Reductions

Reductions in incident duration due to TIM strategies are estimated by the analyst for each incident type. Incident duration is the sum of the detection, verification, response, and clearance times for the incident. A value of 1.00 for the incident duration factor means no change to the incident duration from the "before-ATDM" condition. A value of 0.90 means a 10% (1-0.90) reduction in the incident duration. Since the smallest temporal unit employed in the 2010 Highway Capacity Manual freeway analysis method coded in FREEVAL-ATDM is 15 minutes, the effects of small reductions in incident duration are approximated by increasing the 15-minute capacity of the freeway using the formulae below.

Figure 10: Capacity Gained by Reducing Incident Duration



Source: 2010 Highway Capacity Manual.

As shown in Figure 10, the capacity gained by shortening the incident duration is:

$$CapGained = (c1 - c2) * (1 - x)t$$

Where:

CapGained = capacity gained (vehicles)

C1 = capacity prior to and after incident (vph)

C2 = capacity during incident (vph)

T = duration of incident (hours)

X = proportional reduction in incident duration (unit less)

The new average capacity (caused by reduction of incident duration, but measured over the entire original period of the incident) is:

$$AveCap = \frac{c2 * x * t + c1 * (1 - x) * t}{t}$$

Where:

AveCap = average capacity over original incident duration (vph).

All other variables are same as before.

The original capacity adjustment factor for the incident (y = c2/c1) becomes AveCap/c1

$$AveCapFac = \frac{c2}{c1} * x + (1 - x) = (y - 1)x + 1$$

Where:

AveCapFac = new average capacity adjustment factor reflecting shortened incident duration (unit less)

y = original capacity adjustment factor for incident (unit less)

x = proportional reduction in incident duration (unit less)

A similar approach is used to identify the new average speed adjustment factor of incident with shortened duration.

$$AveSpdFac = \frac{s2}{s1} * x + (1 - x) = (z - 1)x + 1$$

Where:

AveSpdFac = new average speed adjustment factor reflecting shortened incident duration (unit less)

z = original free-flow speed adjustment factor for incident (unit less)

x = proportional reduction in incident duration (unit less)

Demand is not adjusted for the shorter incident duration.

Appendix G: Speed/Capacity for HOV/HOT Lane Strategies

This Appendix provides details on the free-flow speed and capacity adjustments associated with the HOV and HOT lane strategies.

Convert Mixed-Flow to HOV

This strategy converts one or more mixed-flow lanes to HOVs only for a fixed period of time and for a fixed set of freeway sections. This strategy, although not strictly an ATDM strategy, is included to overcome the inability to model existing HOV lanes in the current HCM 2010 freeway method.

The operation and performance of barrier separated (painted or physical), limited access HOV lanes cannot be evaluated with current HCM 2010 freeway methods. The HOV lane must be analyzed as completely integrated with the freeway, with HOVs allowed to enter or leave the HOV lane at any point.

The analyst must specify the number of HOVs plus violators that will use the HOV lane. This value can be approximated as the percent of eligible HOVs on the facility, perhaps discounted a bit in recognition that not all eligible HOVs will use the HOV lane.

The HOV lane or lanes are assumed to be on the left most lane or lanes of the freeway.

The default capacity of an HOV lane is 1,600 vehicles per hour (based on unpublished NCHRP 3-96 research). For two-lane HOV facilities a slightly higher capacity of 1,800 vph/lane may be used. These default values can be overridden in the software by the analyst.

Since, the HCM 2010 freeway method does not recognize individual lane capacities, it is necessary to compute an average capacity for freeway sections with HOV lanes, across all lanes. For the case when there are not enough eligible HOVs plus violators to fill up the HOV lanes, then the capacity of the HOV lane is set at the lower value, the number of eligible HOVs plus violators.

$$AveCap(s) = \frac{CapHOV(s) * HOVlanes(s) + CapMFLanes * MFLanes(s)}{HOVlanes(s) + MFLanes(s)}$$

Where:

AveCap(s) = average capacity per lane for section (s) (vph/ln)

CapHOV(s) = Min (Capacity per HOV Lane, Eligible HOVs per HOV lane) (vph/ln)

HOVlanes(s) = Number of HOV lanes in section (s).

CapMFLanes = capacity per mixed-flow lane (vph/ln).

MFLanes(s) = Number of mixed-flow lanes in section (s)

The free-flow speed and speed-flow curve for HOV lanes are assumed to be the same as for mixed-flow lanes, with the only difference being the capacity of the HOV lanes.

HOV Lanes Opened to All

This strategy opens up the HOV lane(s) to all vehicles. It might be employed in the case of a special event, weather event, incident, or work zone.

Since the HCM 2010 method cannot evaluate barrier separated HOV lane operations, the HOV lane is assumed to be completely accessible to and from the adjacent mixed-flow lanes.

Under this strategy the HOV lanes become just like mixed-flow lanes. The capacity and free-flow speed of the HOV lanes under this strategy then reverts to that of the adjacent mixed-flow lanes.

Convert Lanes to HOT Lanes

This strategy converts one or more mixed-flow lanes to high-occupancy toll (HOT) lanes for a user specified fixed period of time and set of freeway sections.

It is assumed that the toll will be set as necessary to guarantee that the HOT lane(s) are fully utilized. Thus regardless of the number of eligible HOVs that can use the HOT lane for free (or a reduced rate) it is assumed that the HOT lane will always carry its user designated capacity, as long as the adjacent mixed-flow lanes are carrying equal or higher volumes.

Since, the HCM 2010 freeway method does not recognize individual lane capacities, it is necessary to compute an average capacity for freeway sections with HOV lanes, across all lanes.

$$AveCap(s) = \frac{CapHOT(s) * HOTlanes(s) + CapMFLanes * MFLanes(s)}{HOTlanes(s) + MFLanes(s)}$$

Where:

AveCap(s) = average capacity per lane for section(s) (vph/ln)

CapHOT(s) = capacity per HOT lane (vph/ln)

HOTlanes(s) = Number of HOT lanes in section(s).

CapMFLanes = capacity per mixed-flow lane (vph/ln).

MFLanes(s) = Number of mixed-flow lanes in section (s)

The free-flow speed and speed-flow curve for HOT lanes are assumed to be the same as for mixed-flow lanes, with the only difference being the capacity of the HOV lanes.

HOT Lanes Opened to All

This strategy opens up the HOT lane(s) toll free to all vehicles in the case of a special event, weather event, incident, or work zone. The analysis approach and assumptions are the same as for an HOV lane opened to all vehicles.

Appendix H: Speed/Capacity for Shoulder/Median Lane Strategies

This Appendix provides details on the free-flow speed and capacity adjustments associated with the temporary shoulder and median lane strategies.

Open Shoulders As Auxiliary Lanes Between Adjacent On- and Off-Ramps

This strategy involves opening a shoulder lane for use by all vehicles entering at the upstream on-ramp or exiting at the downstream off-ramp. Some through vehicles may temporarily use the auxiliary lane to try and jump ahead of the queue.

The capacity of an auxiliary lane is assumed by the HCM 2010 freeway method to be the same as a regular lane, however; actual utilization of the auxiliary lane may be quite a bit lower than for a through lane. In addition, the HCM 2010 freeway method does not provide a capacity for shoulder lanes. Until such time as the HCM has specific information on the capacities of auxiliary shoulder lanes, this procedure assumes that the capacity of an auxiliary shoulder lane is one-half that of a normal freeway through lane (1,050 vph) (user can override this value in cell X26 of the "30 Lanes" worksheet).

Since, the HCM 2010 freeway method does not recognize individual lane capacities, it is necessary to compute an average capacity for freeway sections with auxiliary shoulder lanes, across all lanes.

$$AveCap(s) = \frac{CapShldr(s) + CapMFLanes * MFLanes(s)}{1 + MFLanes(s)}$$

Where:

AveCap(s) = average capacity per lane for section(s) (vph/ln)

CapShldr(s) = capacity per shoulder lane (vph/ln) (assume only one shoulder lane)

CapMFLanes = capacity per mixed-flow lane (vph/ln).

MFLanes(s) = Number of mixed-flow lanes in section(s)

The number of lanes on the freeway segments between adjacent on- and off-ramps is increased by one for the shoulder lane.

Until such time as the HCM has more specific information for shoulder lanes, free-flow speeds on auxiliary shoulder lanes are assumed in this procedure to be the same as for regular through lanes.

Open Shoulders To Buses Only

This strategy involves opening a shoulder lane to buses only. The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds where buses are allowed on shoulders, with the following exceptions:

- Capacity of the shoulder lane is the number of buses per hour using the shoulder lane or the user specified capacity, whichever is less (user can override the default capacity).

Open Shoulders To HOVs Only

This strategy involves opening a shoulder lane to buses, vanpools, and carpools (HOVs) only. The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds where HOVs are allowed on shoulders, with the following exceptions:

- Capacity of the shoulder lane is the number of HOVs per hour using the shoulder lane or the user specified capacity, whichever is less.

Open Shoulders To All Traffic

This strategy involves opening a shoulder lane to all vehicles.

The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds where all vehicles are allowed on shoulders, with the following exceptions:

- Capacity of the shoulder lane is as specified by the user.

Open Median To Buses Only

This strategy involves opening a median lane to buses only. The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds, with the following exceptions:

- Capacity of the median lane is the number of buses per hour using the shoulder lane or the user designated capacity, whichever is less.

Open Median To HOVs Only

This strategy involves opening a median lane to HOVs (buses, vanpools, carpools) only. The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds, with the following exceptions:

- Capacity of the median lane is the number of HOVs per hour using the shoulder lane or the user designated capacity, whichever is less.

Open Median To All Traffic

This strategy involves opening a median lane to all traffic. The same procedure and assumptions as described above for auxiliary shoulder lanes is used to compute freeway section capacities, lanes, and free-flow speeds, with the following exceptions:

- Capacity of the median lane is as designated by the user.

Appendix I: Speed/Capacity for Ramp Metering Strategies

This Appendix provides details on the free-flow speed and capacity adjustments associated with the HOV and HOT lane strategies.

The 2010 HCM freeway operations analysis method is not sensitive to the effect of ramp metering on the capacity of merge sections. The coded capacity of the freeway merge section is therefore increased by 3% for those days, hours, and locations where there is ramp metering in operation.[5]

Locally Dynamic

For locally dynamic ramp metering an adaptation of the ALINEA,[6] algorithm is used to estimate the ramp metering rate for each analysis period for each scenario.

$$R(t) = (CM - VM(t))/NR$$

Subject to:

$$MinRate < R < MaxRate$$

Equation 9

Where:

R(t) = ramp metering rate for analysis period (t) (vph/ln)

NR = number of metered lanes on ramp.

CM = capacity of downstream section (vph)

VM(t) = volume on upstream section for analysis period (t) (vph)

VR(t) = volume on ramp during analysis period (t) (vph)

QR(t-1) = queue on ramp at end of previous analysis period (t-1) (veh)

QRS = queue storage capacity of ramp (veh)

MinRate = user defined, default value is 240 vph/lane

MaxRate = user defined, default value is 900 vph/lane

The current version of the HCM 2010 freeway analysis procedure does not include ramp storage lengths, so there is no constraint on the estimated metering rates related to ramp queue storage lengths. Should such a capability become available in the future, then the following additional constraint would be applied to the above equation:

$$R(t) > VR(t) + QR(t-1) - QRS$$

Equation 10

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[5] Source for capacity effect of ramp metering: FHWA Ramp Management and Control Handbook, January 2006.

[6] M. Papageorgiou, H. Hadi Salem, and J-M. Blosseville (1991) “ALINEA: A Local Feedback Control Law for On-Ramp Metering,” Transportation Research Record, vol. 1320, pp. 58-64.

Appendix J: Demand Effects of Tolls

The effect of opening day tolls on demand levels can be estimated using the following equation.

$$V_{TL}(t,a) = V_{0,TL}(t,a) + V_{0,NTL}(t,a) \times \frac{[P(t,a)]}{[P_0(t,a)]}$$

Equation 11

$$V_{NTL}(t,a) = V_{0,NTL}(t,a) + V_{0,TL}(t,a) - V_{TL}(t,a)$$

Equation 12

Where

$V_{TL}(t,a)$ = The new demand for the tolled lanes for tolling schedule "t" and analysis period "a" (vph)

P(t,a) = The proportion of vehicles in the nontolled lanes of the facility choosing to use the priced lane under the new toll schedule "t" at the analysis period "a" (unit less)

$V_{0,TL}(t,a)$ = The original (current) demand for tolled lanes under original toll schedule "t" at analysis period "a" (vph)

$P_0(t,a)$ = The proportion of vehicles in the nontolled lanes of the facility that chose to use the priced lane under the original toll schedule "t" (if any) at the analysis period "a" (unit less)

$V_{NTL}(t,a)$ = The new demand for nontolled lanes under new toll schedule "t" at analysis period "a" (vph)

$V_{0,NTL}(t,a)$ = The original demand for nontolled lanes under original toll schedule "t" at analysis period "a" (vph)

The proportion of vehicles on the facility choosing to use the priced lane is estimated using the following equation:

$$P(t,a) = 1 - \Phi\left(\frac{\ln\left(\frac{t(a)}{MS(a)}\right) - \mu}{\sigma}\right)$$

Equation 13

Where:

P(t,a) = Proportion of vehicles on the facility that will choose the priced lane during analysis period (a).

t(a) = the toll for analysis period "a" ($). t(a) > 0

MS(a) = minutes saved by taking the tolled lane (minutes). MS(a) > 0

converted into dollars paid per minute saved using priced lane during analysis period (a), subject to the constraint that t(a) > 0. (in units of dollars/minute)

Φ = (Phi), cumulative log-normal distribution

μ = (mu), the log of the average value of time (for default use 3.43)[7]

σ = (sigma), the log of the standard deviation of value of time (for default use 0.467)

If the predicted demand for the tolled lanes exceeds their capacity in any analysis period "a" then the relative time savings between tolled and untolled lanes needs to be recomputed and iterated to an equilibrium solution.

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[7] Value provided is for default use only. For specific values of time consult the U.S. DOT, office of the Assistant Secretary for Transportation Policy web site: http://www.dot.gov/policy.

Appendix K: Long-Term Demand Effects

The demand adjustment model presumes that demand will respond to two factors related to weather, work zones and incidents; the added delay to pass through the work/incident zone and the proportion of travelers that are aware of the delay prior to entering the facility. The demand adjustment model is based on a travel time elasticity which suppresses total demand, a route diversion parameter, and a modifying factor based on the percentage of the drivers aware of the delay prior to entering the facility.

$$V = V_0 \times \left(\frac{T_0 + D}{T_0} \right)^{\beta} \times \exp[\gamma \times D] \times [TIMP]$$

Equation 14

Where

V = The new demand (vph)

V_0 = The original (current) demand (vph)

T_0 = The original (current) average door to door trip length for users of facility (min)

D = Delay, the change in travel time between the original and future condition (min).

β = Beta, travel time elasticity (default is -0.2)

γ = Gamma, route diversion parameter (see Table 46).

TIMP = Traveler Information Market Penetration – proportion of drivers on facility that are fully and accurately aware of the delay prior to entering the facility (0-1). This will be a function of the timeliness, accuracy, quality, and detail of the information provided to the drivers on the facility.

For the average door to door trip length of facility users, use data from local household survey or regional travel demand model. Lacking that data, 22.9 minutes, the national average commute trip time, can be used as a default (FHWA, Summary of Travel Trends – 2009 National Household Travel Survey).

The selection of the traveler information market penetration (TIMP) will be sensitive to the degree to which the agency pushes weather, work and incident zone delay information to the web and mobile devices, and the degree to which drivers take advantage of it. The TIMP will also be sensitive to the timeliness, accuracy, quality and detail of the information provided to the traveler (for example alternate routes and/or comparative travel times). Obviously the greater the amount of advance warning that can be given, and the greater the number of media outlets will increase the market penetration rate of the work/incident zone information.

For the route diversion parameter (Gamma) select a value that results in reasonable estimates of route diversion for the selected facility location. This will be highly dependent on the availability of parallel routes with sufficient capacity, and therefore no default value can be provided. Table 46 provides a recommended Gamma diversion parameter according to the amount of extra delay that would be incurred taking the alternate route (as compared to current conditions on the freeway). For example, if the extra travel time of taking the alternate route is 5 minutes (when compared to current freeway travel time conditions), then a Gamma parameter value of -0.139 would ensure that 50% of the drivers will switch to the alternate route when delays on the freeway increase by 5 minutes over current levels.

Table 46: Appropriate Gamma Diversion Parameters According to Delay of Alternate Route

Extra Delay Taking Alternate Route (min)	Gamma Parameter to Equalize Diversion between Freeway and Alternate Route	Extra Delay Taking Alternate Route (min)	Gamma Parameter to Equalize Diversion between Freeway and Alternate Route
1	-0.693	11	-0.063
2	-0.347	12	-0.058
3	-0.231	13	-0.053
4	-0.173	14	-0.050
5	-0.139	15	-0.046
6	-0.116	16	-0.043
7	-0.099	17	-0.041
8	-0.087	18	-0.039
9	-0.077	19	-0.036
10	-0.069	20	-0.035

Note: These Gamma diversion parameters will result in a 50:50 split between the freeway and the alternate route when the travel times on freeway and alternate route are equal.

The values in this table are computed using the following equation:

$$\gamma = \frac{\ln[1 - x]}{D}$$

Equation 15

Where

γ = The Gamma diversion parameter to achieve the target diversion proportion (x) of traffic to alternate route when travel times on freeway and alternate route are identical.

x = the target proportion of freeway traffic diverted to the alternate route when travel times on the freeway and alternate route are equal.

D = The extra travel time taking the alternate route (minutes).

Employer-Based TDM Plans

The analyst selected values for the labor pool covered by participating employers and the expected reduction in SOV use by participating employees are used in the following equation to estimate the reduction in facility demand to be achieved by employer-based TDM plans.

$$V = V_0 \times [1 - PHBW \times LPP \times SOVR]$$

Equation 16

Where

V = The new demand (vph)

V_0 = The original (current) demand (vph)

PHBW = Proportion commuters in traffic stream (unit less). Default is 0.50

LPP = Proportion of labor pool covered by participating employers. (unit less)

SOVR = Expected proportional reduction in SOV use by employees at participating employers (unit less)

The demand effects of various employer-based TDM program elements can be estimated using sketch planning models such as TRIMMS (University of South Florida, available at http://www.nctr.usf.edu/clearinghouse/software.htm).

For quick estimation purposes, Table 47 can be used to approximate the likely effect of an employer-based TDM program as a function of the percent of the county workforce represented by the employers participating in the TDM program. This table was constructed for employer-based TDM programs consisting of the following elements:

- Alternative or flexible work schedules;
- Telework;
- Rideshare program;
- Car sharing/bike sharing program;
- Guaranteed ride home program;
- Education Program on Commute Alternatives;
- Implementation of a commute trip reduction program;
- Participate in/create/sponsor a transportation management association;
- Employer Subsidies/Financial Incentives:
  - Vanpool/carpool/parking-cash out financial incentives – between $2.50/trip and $5.00/trip; and
  - Public transit financial incentive of $2/trip.

One additional option evaluated and shown in the table was adding a charge of $15/day for on-site employee auto parking (that was previously free) to the employer's TDM program.

Table 47: Prototypical Effectiveness of TDM at Auto Demand Reduction

Percent of County Workforce Participation in TDM	Parking Pricing	Reduction in Peak Period Auto Trips on Facility
15%	N/A	1.5%
30%	N/A	3.0%
45%	N/A	4.5%
45%	$15/day	5.5%

Note: Adapted from: Dowling Associates, I-580 Interregional Multimodal Corridor Study, San Joaquin Council of Governments, 2011.

Appendix L: Designing an ATDM Program

ATDM strategies are combined into an overall ATDM program for addressing challenges to the efficient operation of the highway system. The ATDM program will have different plan elements to address specific challenges to the system.

- The travel demand management element (TDM) will address how demand management will be used to address recurring congestion on the facility.
- The weather traffic management plan element (W-TMP) will identify the ATDM strategies to be employed during weather events. The W-TMP will have a TDM component targeted to special weather events.
- The traffic incident management (TIM) element will identify the ATDM strategies to be employed for incidents. The TIM will have a TDM component to manage demand on the facility during incidents.
- The work zone traffic maintenance plan (WZ-TMP) element will identify the ATDM strategies to be employed for work zones. The WZ-TMP will have a TDM component to manage demand while work zones are present.
- Facilities located next to major sporting and entertainment venues may also have a special event management plan with ATDM strategies identified to support management of traffic before and after major events.

Travel Demand Management Plans

The FHWA web site, Travel Demand Management Toolbox (FHWA), provides resources to help manage traffic congestion by better managing demand. These resources include publications, web links, and training offerings.

According to the FHWA publication, Mitigating Traffic Congestion (Association for Commuter Transportation, 2004), demand management strategies include:

- technology accelerators;
  - real time traveler information;
  - national 511 Phone number;
  - electronic payment systems;
- financial incentives;
  - tax incentives;
  - parking cash-out;
  - parking pricing;
  - variable pricing;
  - distance-based pricing;
  - incentive reward programs;
- travel time incentives;
  - high-occupancy lanes;
  - signal priority systems;
  - preferential parking;

- marketing and education;
  - social marketing;
  - individualized marketing;
- mode targeted strategies;
  - guaranteed ride home;
  - transit pass programs;
  - shared vehicles;
- departure time targeted strategies;
  - worksite flextime;
  - coordinated event or shift scheduling;
- route targeted strategies;
  - real-time route information;
  - in-vehicle navigation;
  - web-based route-planning tools;
- trip reduction targeted strategies;
  - employer telework programs and policies;
  - compressed work week programs;
- location design targeted strategies
  - transit-oriented development;
  - live near your work; and
  - proximate commute.

The Mitigating Traffic Congestion guide should be consulted for more information on designing the TDM element of an ATDM program.

Weather Responsive Traffic Management Plans

Weather Responsive Traffic Management (WRTM) involves the implementation of traffic advisory, control, and treatment strategies in direct response to, or in anticipation of, developing roadway and visibility issues that result from deteriorating or forecasted weather conditions (Gopalakrishna, Cluett, Kitchener, & Balke, 2011).

Weather responsive traffic management strategies include:

- motorist advisory, alert and warning systems;
- speed management strategies;
- vehicle restrictions strategies;
- road restriction strategies;
- traffic signal control strategies;
- traffic incident management;
- personnel/asset management; and
- agency coordination and integration.

FHWA's report, Developments in Weather Responsive Traffic Management Strategies (Gopalakrishna, Cluett, Kitchener, & Balke, 2011) should be consulted for additional information on the design and selection of weather responsive traffic management strategies.

Traffic Incident Management Plans

FHWA's, Traffic Incident Management Handbook, (Owens, et al., 2010) provides information on the design of traffic incident management plans.

Traffic incident management (TIM) is "the coordinated, preplanned use of technology, processes, and procedures to reduce the duration and impact of incidents, and to improve the safety of motorists, crash victims and incident responders." An incident is "any nonrecurring event that causes a reduction in capacity or an abnormal increase in traffic demand that disrupts the normal operation of the transportation system (Balke, 2009). Such events include traffic crashes, disabled vehicles, spilled cargo, severe weather, and special events such as sporting events and concerts. ATDM strategies may be included as part of an overall incident management plan to improve facility operations during and after incidents.

An agency's incident management plan documents the agency's strategy for dealing with incidents. It is, in essence, a maintenance of traffic plan (MOTP) for incidents, unplanned work zones. The responses available to the agency are more limited for incident management, and by definition, must be real time, dynamic responses to each incident as it presents itself. The agency's incident maintenance of traffic plan (I-MOTP) ensures that adequate resources are prepositioned and interagency communications established to respond rapidly and effectively to an incident. The TIM plan may include measures in effect 24 hours a day, 7 days a week, weekdays only, weekday peak periods, or any other period of time or days of the week that are the focus of the incident management plan.

Incidents Defined and Classified

An incident is an unplanned disruption to the capacity of the facility. Incidents do not need to block a travel lane to disrupt the capacity of the facility. They can be a simple distraction within the vehicle (spilling coffee) or off on the side of the road or the reverse direction of the facility.

Incidents can be classified according to the response resources and procedures required to clear the incident. This helps in identifying strategic options for improving incident management.

The 2009 Manual on Uniform Traffic Control Devices (MUTCD) (FHWA) classifies incidents according to their expected duration (see section 6I.01 of the 2009 MUTCD).

- "Extended" duration incidents are those that are expected to persist for over 24 hours and should be treated like work zones (Section 6I.01 of MUTCD).
- "Major" incidents have expected durations of over 2 hours.
- "Intermediate" incidents have expected durations of 0.5 hours up to and including 2 hours.
- "Minor" incidents are expected to persist for less than 30 minutes.

Stages of Incident Management

Incident management is the systematic approach, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents. There are several stages to incident management:

- detection;
- verification;
- response;
- motorist information;
- site management:
  - traffic management;
  - investigation; and
  - clearance.

Detection is the first notice that the agency receives that there may be an incident on the facility. Detection may occur via 911 calls, closed circuit TV cameras or detector feeds to a TMC, or maintenance/enforcement personnel monitoring the facility.

Verification confirms that an incident has occurred, collects additional information on the nature of the incident, and refines the operating agency's understanding of the nature, extent, and location of the incident for an effective response.

A **response** is selected after an incident is verified and the appropriate resources are dispatched to the incident. A decision is also made as to the dissemination of information about the incident to the motoring public.

Motorist information informs drivers not at the site about the location and severity of the incident so as to enable drivers to better anticipate conditions at the site and give them the opportunity to divert and avoid the site altogether.

Site management refers to the management of resources to remove the incident and reduce the impact on traffic flow. This stage involves three major tasks: traffic management, investigation, and clearance.

- **Traffic management** is the control of and safe movement of traffic through the incident zone.
- **Investigation** of an incident documents the causes of traffic incidents for legal and insurance purposes.
- **Clearance** refers to the safe use and timely removal of any wreckage or spilled material from the roadway.

An Incident Management Plan has the following strategic and tactical program elements (Owens, et al., 2010):

- Management Objectives and Performance Measurement;
- Designated Interagency Teams Membership, Roles, and Responsibilities;
- Response and Clearance Policies and Procedures; and
- Responder and Motorist Safety Laws and Equipment.

Incident Response and Clearance Strategies

The Incident Management Plan will designate the responder roles and responsibilities. It will establish an Incident Command System with a unified command across agencies. It will identify who is responsible for bringing which equipment and resources to the incident site. It will establish response and clearance procedures by responding agency and by incident type. It will identify existing state and local laws that apply to incident clearance procedures.

Table 48 presents a menu of possible incident management strategy improvements that an agency may wish to evaluate using the ATDM Analysis procedure. This table is a summary of the FHWA book, Best Practices in Traffic Incident Management (Carson J. L., 2010). The expected effect of each class of strategies on highway capacities and speeds are included in this table as well.

Table 48: Possible Incident Management Strategies and Their Effects on Capacity and Speed

Strategies	Description	Likely Effects
Improved Detection and Verification Strategies	Closed circuit TV, routine service patrol, or other continuously monitored incident detection system to more quickly spot incidents and verify the required resources to clear the incident. Also: Enhanced 911, automated positioning systems, motorist aid call boxes, automated collision notification systems.	Shorten incident duration by shortening detection and verification delays.
Traveler Information System Strategies	511 systems, traveler information web sites, media partnerships, dynamic message signs, standardized DMS message sets and usage protocols to improve the information available to traveler.	Demand reduction in advance of the incident zone.
Response Strategies	Personnel/equipment resource lists, towing and recovery vehicle identification guide, instant tow dispatch procedures, towing and recovery zone-based contracts, enhanced computer aided dispatch, dual/optimized dispatch procedures, motorcycle patrols, equipment staging areas or prepositioned equipment.	Shorten incident duration by shortening response and clearance times.
Scene Management and Traffic Control Strategies	Incident command system, response vehicle parking plans, high-visibility safety apparel and vehicle markings, on-scene emergency lighting procedures, safe/quick clearance laws, effective traffic control through on-site traffic management teams, overhead lane closure signs, variable speed limits, end of queue advance warning systems, alternate route plans.	Shorten incident duration by shortening response and clearance times. Reduce unnecessary lane closures. Reduce secondary incident probabilities.
Quick Clearance and Recovery Strategies	Abandoned vehicle laws, safe/quick clearance laws, service patrols, vehicle mounted push bumpers, incident investigation sites, noncargo vehicle fluid discharge policy, fatality certification/removal policy, expedited crash investigation, quick clearance using fire apparatus, towing and recovery quick clearance incentives, major incident response teams.	Shorten incident duration by shortening response and clearance times.

Source: Adapted from: FHWA, Best Practices in Traffic Incident Management, FHWA-HOP-10-050, September 2010.

Work Zone Transportation Management Plans

Work zone management has the objective of safely moving traffic through the working area with as little delay as possible consistent with the safety of the workers, the safety of the traveling public, and the requirements of the work being performed. Transportation management plans (TMPs) are a collection of administrative, procedural, and operational strategies used to manage and mitigate the impacts of a work zone project.

The work zone maintenance of traffic plan (WZ-MOTP) may have three components: A Temporary Traffic Control plan, a Transportation Operations plan, and a Public Information plan. The temporary traffic control plan describes the control strategies, traffic control devices, and project coordination. The transportation operations plan identifies the demand management, corridor management, work zone safety management, and the traffic/incident management and enforcement strategies. The public information plan describes the public awareness and motorist information strategies (Balke, 2009). ATDM strategies can be important components of a TMP (Jeannotte & Chandra, 2005).

The Work Zone Maintenance of Traffic Plan (WZ-MOTP) codifies the agency's management strategy. The WZ-MOTP has the following elements.

- **Construction Approach** – staging, sequencing, lane and ramp closure alternatives, alternative work schedules (night, weekend).
- **Traffic Control Operations** – A mix of dynamic (ATDM) and static measures consisting of speed limit reductions, truck restrictions, signal timing (coordination and phasing), reversible lanes, physical barriers.
- **Public Information** – A mix of dynamic (ATDM) and static pre-trip and en-route information (e.g., 511, newspapers, meetings, web sites, CCTV over the web), plus on-site information signing such as, static signs, changeable/variable message signs (CMS/VMS), and highway advisory radio (HAR).
- **Travel Demand Management (TDM)** – employer-based and other incentives (in addition to public information) for use of alternative modes of travel, including park and ride.
- **Incident Management and Enforcement** – Generally ATDM measures specified in an incident management plan (I-MOTP), such as: traffic management centers, intelligent transportation system (ITS), emergency service patrols, Hazmat teams, and enhanced police enforcement. A particularly aggressive I-MOTP may be put in place for work zones.

Construction Approach

The WZ-MOTP must consider several alternative construction approaches (including traffic maintenance) and finally recommend the construction approach that best meets the agency's objectives for the construction project.

Traffic maintenance approaches to be considered in the WZ-MOTP include:

1. Completely close work area for short time versus partial closure for longer time;
2. Nighttime versus daytime lane closures; and
3. Off-peak versus peak lane closures.

Traffic Control Operations

The traffic control element of the MOT plan specifies work zone speed limit reductions, signal timing changes (if needed), reversible lanes (flagging, etc.), and the locations of physical barriers and cones. The traffic control elements may be dynamic, responding in real time to changing conditions, or they may be more static, operating at prespecified times of the day.

Section 6G.02 of the Manual on Uniform Traffic Control Devices (MUTCD)[8] defines work zone types according to the duration, and time of day.

- Duration Type A: Long-term stationary is work that occupies a location more than 3 days.
- Duration Type B. Intermediate-term stationary is work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour.
- Duration Type C. Short-term stationary is daytime work that occupies a location for more than 1 hour within a single daylight period.
- Duration Type D. Short duration is work that occupies a location up to 1 hour.
- Duration Type E. Mobile is work that moves intermittently or continuously.

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[8] FHWA, Manual of Uniform Traffic Control Devices, 2009, http://mutcd.fhwa.dot.gov/, accessed November 14, 2011.

Work zones are further categorized by the MUTCD (see section 6G.03) according to the location on the facility. Work zones within the traveled way (Location Type E) are further subdivided by facility type.

- Location Type A: Outside the shoulder (Section G6.06);
- Location Type B: On the shoulder with no encroachment (Section G6.07);
- Location Type C: On the shoulder with minor encroachment, (leaving at least a 10-foot lane) (Section G6.08);
- Location Type D: Within the median, (Section G6.09); and
- Location Type E: Within the traveled way of:
  - Section 6G.10 –Two Lane Highway;
  - Section 6G.11 –Urban Street;
  - Section 6G.12 –Multilane Non Access Controlled Highway;
  - Section 6G.13 – Intersection; and
  - Section 6G.14 –Freeway or Expressway.

Each work zone type has an associated typical application of temporary traffic controls in the MUTCD. These are described in 6H-1 of the MUTCD.

Public Information Element

The public information element is intended to provide the public with pre-trip and en-route information, and preconstruction and during construction information on the work zone so that the public can plan accordingly. The intent is to encourage those who can, to reschedule or reroute their trip to avoid the work zone during periods of peak closures. Public information includes 511 alerts, press interviews, public information meetings, project update web sites, as well as on-site web accessible closed circuit cameras (CCTV), variable message signs (VMS) and highway advisory radio (HAR).

Travel Demand Management Element

The travel demand management (TDM) identifies incentives that will be provided for alternative modes, such as park and ride lots, in coordination with the public information element. The difference between the public information element and the TDM element is that the public information provides neutral information leaving it to the traveler to choose how to respond. The TDM element provides monetary and service incentives to encourage a particular subset of choices.

Incident Management and Enforcement Element

Incident management includes the development of incident management plans for the work zone. These plans describe the coordination with traffic management centers, the employment of ITS (Intelligent Transportation System) devices, deployment of emergency service patrols in the work zone, and enhanced police enforcement. Enforcement may be reinforced with speed limit feedback signs and other devices.

Special Event Management Plans

Special event management deals with moving people and traffic to and from special event locations, such as a sports stadium, concert hall, or an arena. The objective is to get people and traffic onto and off of the site with minimal backups onto the public transportation system and in a reasonable amount of time. Traffic control officers, temporary cones and signs, reversible lanes, and special signal control plans are often part of a special event management plan. (Carson & Bylsma, 2003)

A special event management plan typically has the following components:

- Before Event Ingress Control;
- During Event Access Control; and
- Post Event Egress Control.

The Special event management plan will deploy a combination of temporary signing, lane controls, signal timing plans, and personnel, to move traffic into the event venue and out of the venue, much like a short-term work zone. The event management plan will have different gradations of deployment depending on the expected attendance at the event.

Appendix M: The Equilibrium Effects of ATDM

The equilibrium effects of ATDM come into play as travelers on other facilities in the area recognize the time and reliability savings of the ATDM improvements on the subject facility and shift their route choice, time-of-day choice, and their mode choice to take advantage of the improved operations on the subject facility. This effect may be called by some, "induced demand."

For the purposes of estimating the benefits of ATDM investments it is not strictly necessary to account for the equilibrium effects of ATDM, because travelers drawn to the facility from other facilities (or modes or times of day) do so because they also experience a net benefit from the ATDM improvements to the subject facility. In addition, their leaving the other facilities also improves the operation of the other facilities for those drivers remaining on the other facilities.

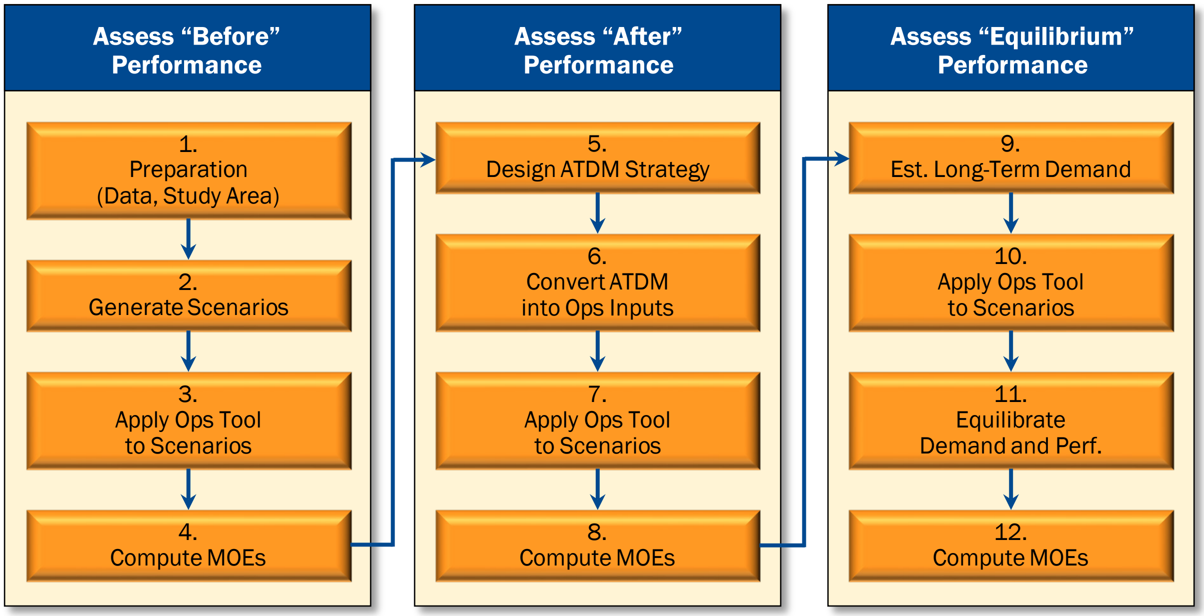
Accounting for the equilibrium effects of ATDM is important when one wishes to obtain a more accurate estimate of facility performance after drivers in the area have adapted to the improved conditions.

Overview of Equilibration Process

The steps of the equilibration process are as follows (also see Figure 11):

1. Estimate Long-Term Demand Shifts: Shifts in demand (destination choice, mode choice, time-of-day choice and route choice) are estimated based on the predicted percentage change in mean travel time, mean travel cost, and travel time reliability caused by the ATDM strategy.
2. Apply Operations Analysis Tool to Scenarios (Long-Term): The same operations analysis model is applied using the new demand estimates to compute performance.
3. Equilibrate Demand and Performance: The change in travel time predicted with the new demands is compared to the change in Opening Day travel times which was used to predict the new demands. The estimated new demand values are equilibrated until they no longer change significantly between iterations.
4. Compute MOEs (Long-Term): The results output by the operations analysis tool for long-term, after equilibration of the new demands, are combined to yield the desired MOEs. The analyst assesses the long-term performance results and decides if the ATDM strategy needs to be fine-tuned and reanalyzed.

Figure 11: Flow Chart of ATDM Analysis Process – With Equilibration



Source: Cambridge Systematics, Inc.

Step 9: Estimate Long-Term Effects

The six-month effect of ATDM on facility performance (after travelers have had a chance to adjust to the improved conditions) is determined by computing the effect of the facility performance improvements on demand. The revised demand is used to reestimate the travel times with ATDM. The revised travel times and demands are iterated until a new equilibrium is achieved.

Highway capacity and operational improvements, including ATDM strategies, will affect demand by improving travel times. It is important to consider the demand effects when evaluating the environmental impacts of capacity and operational improvements. It is especially important for evaluation of ATDM strategies because they explicitly seek to control demand so as to improve system operating efficiency.

In the context of highway operational improvements such as those associated with ATDM, long-term is considered 5 to 6 months after the operational and/or capacity improvements have been implemented. Travelers have had sufficient time to become accustomed to the new facility travel times and have adjusted their behavior (start times, destinations, modes, and routes) to take advantage of the new conditions.

The long-term demand effects are best estimated using a regional travel demand model, but this can frequently be impractical when conducting facility-specific studies. In addition, regional demand models often have difficulty accurately representing congested conditions on highways and the effects of operational improvements. A sketch planning model approach is consequently provided for when it is not feasible to use a regional demand model.

The forecasted new demands must be equilibrated with the demands used to estimate the travel times until the differences between the demands used to estimate the travel times, and the demands estimated from the travel times are negligible.

Overview of Long-Term Demand Method

The Opening Day demands and travel times are compared to the "Before" demands and travel times. An estimated long-term demand is produced. The estimated long-term demand is compared to the opening day demand. If the two demands are sufficiently different the HCM method is applied to the long-term demands to obtain long-term travel times and the new travel times used to produce a second estimate of the long-term demand. These computations are repeated until equilibrium in the demand estimates is achieved. The last iteration travel time and demand estimates are reported out as the long-term performance of the facility with highway capacity and/or operational improvements.

Utilization of Regional Demand Models

Regional demand models devote a great deal of effort to predict travel demands over the large geographic areas necessarily to fully capture travel behavior. As a consequence, regional demand models sacrifice accuracy and precision in the modeling of the traffic operations of individual segments of individual highway facilities.

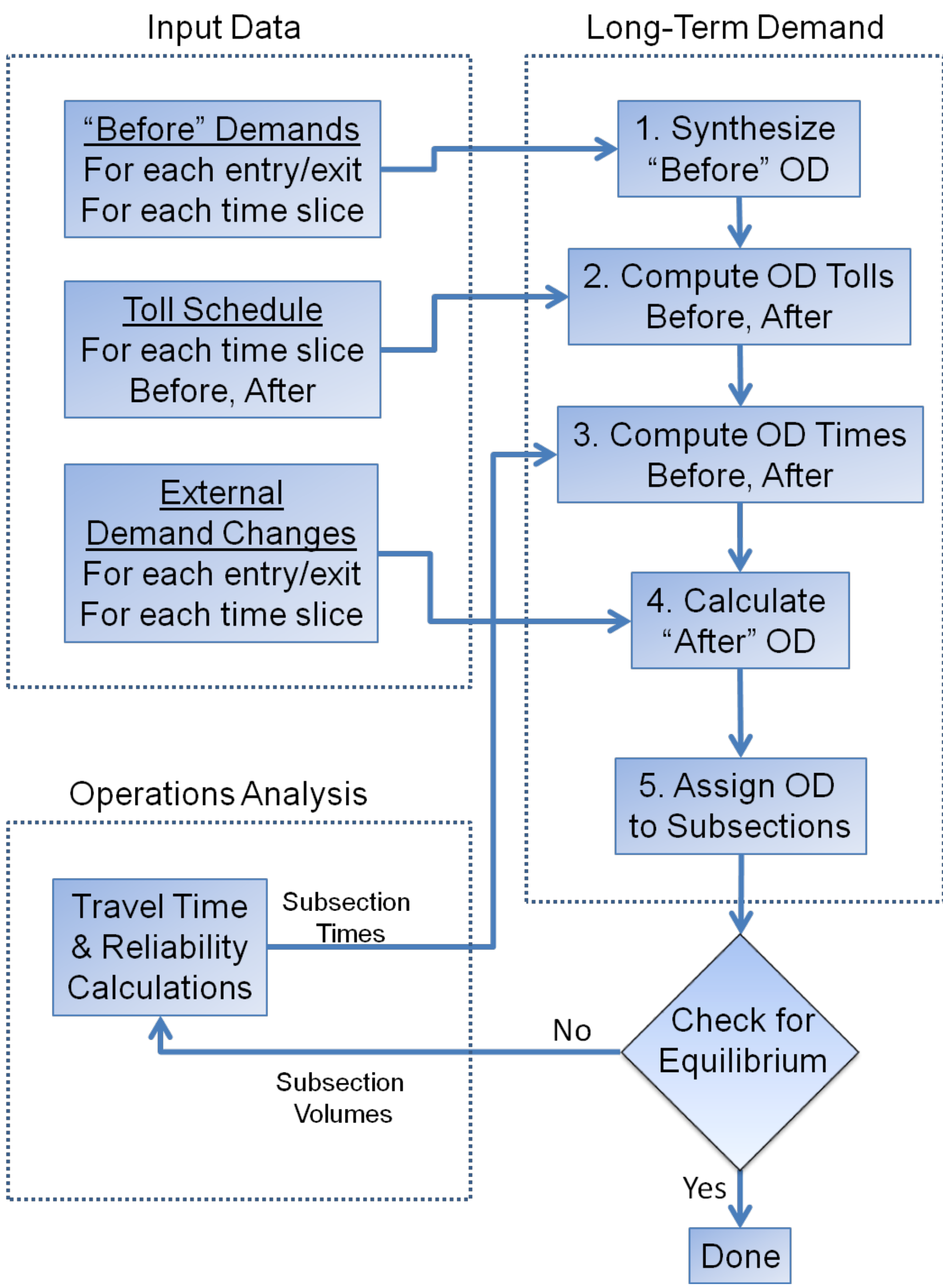
If a regional demand model is to be used to model the demand effects of capacity and operational improvements it is necessary to integrate the demand model with a traffic operations model of sufficient precision to accurately model the traffic operations effects of the capacity and operational improvements. The two models must then be equilibrated to ensure that the travel times used to estimate the demands in the demand model are the same as the demands used to estimate the travel times in the traffic operations model.

The integration and equilibration of two models can be quite resource-intensive, thus an alternative sketch planning approach to demand modeling is presented in the next section. The full regional demand modeling approach will provide the more comprehensive and reliable estimates of demand changes; however, when it is not feasible to apply the full demand model, a sketch planning approach is much superior to assuming that demand does not change at all.

Sketch Planning Methodology

An overview of the sketch planning methodology for estimating long-term demand is presented in Figure 12. The origin-destination (OD) table for the facility is estimated from the segment flows. The facility toll schedule (if any) is converted to the equivalent OD toll table. The facility segment travel times are converted to OD travel times. The differences between the before and after travel times and tolls are used to estimate the new OD table of demands. The new demands are assigned to the appropriate facility segments. The new "after" demands are compared to the "before" demands. If they are within the specified closure criteria, the analysis is complete. If not, then the operations analysis tool is used to recompute the facility segment travel times using the new demands. The new "after" travel times are fed back to the demand module. The process is repeated until the change in demands drops below the closure criteria.

Figure 12: Sketch Planning Model Flow Chart



Source: Cambridge Systematics, Inc.

Step 9.1: Synthesize Facility OD Tables

The facility section demands must be converted to origin-destination (OD) table of demands for the facility. This is necessary so that each vehicle's entire trip experience on the facility is accounted for in evaluating changes in demand.

If HOV lanes are to be evaluated, then separate OD tables should be constructed for HOVs and for SOVs.

Figure 13 and Figure 14 illustrate origin-destination numbering schemes for a typical freeway and a typical street. A freeway may be evaluated one direction at a time when generating the OD table. An arterial street must be evaluated for both directions of travel when generating the OD table.

The OD table for each time slice (and each mode – HOV, SOV) within the scenario is estimated based on the entry and exit demands for the facility and the relative distance between the two points.

$$Tij = \frac{Ti * Tj * f(ij)}{\sum_j Tj * f(ij)}$$

Equation 17

Where:

Tij = Vehicle-trips entering facility at origin "i" and exiting at destination "j."

Ti = Vehicle-trips entering facility at origin "i."

Tj = Vehicle-trips entering facility at destination "j."

L(ij) = the distance in feet between origin "I" and destination "j"

f(ij) = distance weighting factor.

For Arterials:

$f(ij) = 1$ for all i<> j

$f(ij) = 0$ for all i = j (assume no U-turns)

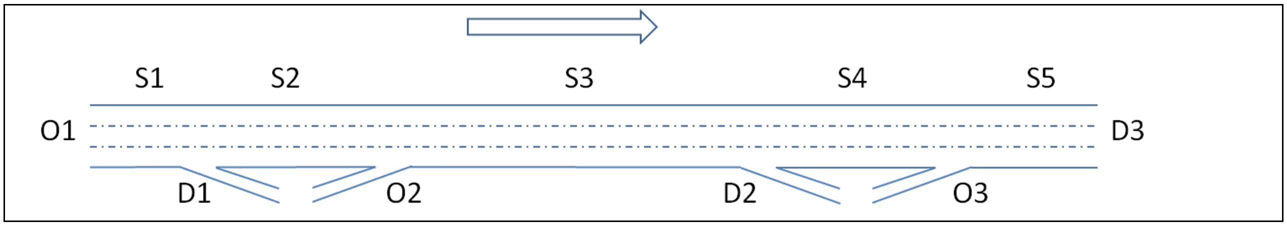
For Freeways:

$f(ij) = \exp\left(-\frac{4}{L(ij)}\right)$ for "j" = off-ramp

$f(ij) = 1$ for "j" = mainline out

For freeway facilities under 5 miles in length one might assume that the ramp to ramp OD demands are small enough that they can be neglected. In this case, then 100% of the on-ramp demands go to the mainline destination, and 100% of the off-ramp demands come from the mainline origin. Of course, if the analyst has information on specific local circumstances causing significant on-ramp to off-ramp demands, then that information should be employed in the construction of the facility OD table by time slice.

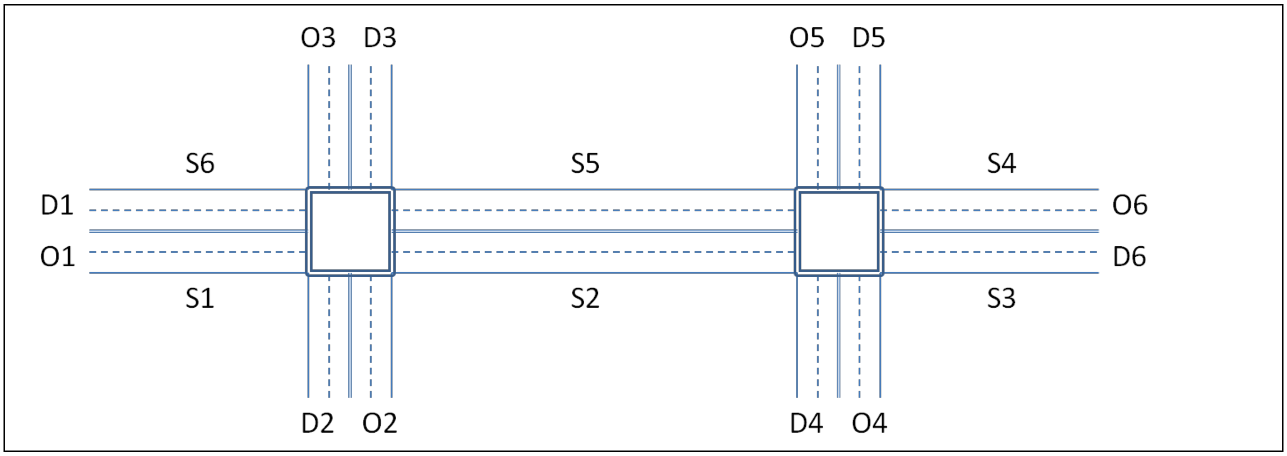
Figure 13: Example Freeway Facility Origins and Destinations



Source: Cambridge Systematics, Inc.

Key: O1 = Origin #1; D1 = Destination #1; S1 = Directional Section #1

Figure 14: Example Street Origins and Destinations



Source: Cambridge Systematics, Inc.

Key: O1 = Origin #1; D1 = Destination #1; S1 = Directional Section #1

Step 9.2: Convert Schedule of Tolls to OD Tolls

The schedule of tolls for the facility or HOT lane (if any) is converted to the equivalent origin-destination toll for the facility for each time slice.

Step 9.3: Compute OD Travel Times

The facility section travel times are summed up to obtain facility origin-destination (OD) travel times. The facility travel times are then extrapolated to full trip travel times. This is necessary because this sketch planning approach applies full trip elasticities.

Step 9.3A: Convert Segment Travel Times to Facility OD Travel Times

The facility section travel times are summed up to obtain facility origin-destination (OD) travel times. If there are multiple paths to a destination, then the travel times for the shortest travel time path are summed.

For the purpose of computing the shortest travel time path, tolls, if any, are converted to the equivalent travel time in minutes by dividing the toll by the driver's value of time (VOT). The value of time can be computed based on average income for the area and using FHWA's TRUCE program (http://ops.fhwa.dot.gov/tolling_pricing/value_pricing/tools/truce_model_guide.htm). Values of Time for selected large urban areas are provided in Table 49.

Table 49: Value of Time for Major Urban Areas

Major Urban Area	Los Angeles	Chicago	Washington, D.C.
Median household Income, 2005	$50,851	$53,838	$74,649
Average cost of time per vehicle-hour:			
Cars	$19.00	$19.70	$26.39
Trucks	$61.55	$67.25	$64.30
All vehicles	$21.17	$23.08	$28.05

Source: FHWA TRUCE

Step 9.3B: Extrapolate Facility OD Travel Times to Complete Trip Times

The facility OD travel times are extrapolated to full trip travel times (sum of on-facility and off-facility trip times). The traveler's full trip travel time is assumed to be a function of the amount of time they spend on the facility. This computation is applied for each time slice within the scenario.

$$TT(ij) = T_R(ij) + \frac{T_F(ij)}{\left(1 + \frac{0.65T_R(ij)}{T_F(ij)}\right)}$$

Equation 18

Where

TT(ij) = Full trip travel time for facility travelers using facility to go from "i" to "j" (min.).

T_F (ij) = travel time on the facility for the entry-exit pair (min)

T_R (ij) = peak period regional average travel time (min)

Note that when T_F is small, average total trip time is approximately equal to the regional average trip time. As T_F increases, the average total trip time increases so that travel time off the facility is always greater than zero.

Step 9.3C: Compute Reliability Weighted Trip Times

SHRP 2-L04, Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools, will be addressing the effects of travel time reliability on demand, however, that research will not be completed until February 2012. So for the interim the following equation is recommended to calculate travel time equivalents for a trip:

$$TTE = TT(mean) + a * [TT(80\%) - TT(50\%)]$$

Equation 19

Where:

TTE = The travel time equivalent on the facility for the entry-exit pair (min)

TT(mean) = The mean travel time (min)

"a" = Calibration parameter (default is 1.00)

TT(80%) = The 80th percentile travel time (min)

TT(50%) = The 50th percentile travel time (min)

Step 9.4: Compute Demand Response

For each time period, entry-exit pair, vehicle class, and lane class, the change in volume due to the change in travel time equivalents is calculated using a mixed power-exponential function.

$$V = V_0 \times \left(\frac{T}{T_0} \right)^{\beta} \times \exp\left[\gamma \times \left(T - T_0 \right) \right]$$

Equation 20

Where

T_0 = The "Before" travel time equivalents (min)

V_0 = The "Before" demands (veh)

T = The "After" travel time equivalents (min)

V = The "After" demands (veh)

β = Beta, travel time elasticity (default is -0.2)

γ = Gamma, route diversion parameter (default is 0.0)

This equation is applied three times for each OD pair and time slice: once to nontoll-paying SOVs, once to toll-paying SOVs, and once to HOVs. If HOVs are charged a toll (so that some switch to the HOT lane and some stay in the all-purpose lanes), then it would be applied four times.

The route diversion effects (captured by γ (Gamma) in the above equation) will vary greatly from situation to situation, depending on the characteristics of alternative routes. If the facility in question is an isolated freeway that operates at speeds much higher than parallel arterials, we would expect route diversion to be minimal (the value of Gamma would be near zero). However, if there are parallel freeways nearby or if the freeway is congested so that its speeds may not be that much greater than parallel arterials, then route diversion could be very significant.

Step 10: Apply Operations Tool

The selected HCM traffic operations analysis tool is applied to the scenarios using the new demands estimated in the previous step. The traffic operations analysis tool is applied separately to each scenario to compute predicted segment travel times for the facility under each scenario.

Step 11: Equilibrate Results

Since the previous step will result in new estimates of travel times for the new demands, it is necessary to equilibrate the results until the predicted demand changes are consistent with the predicted travel time changes used to estimate the demand changes. The equilibration process proceeds as follows:

- For each cell in each OD table for each time slice compute the ratio of the new predicted trips to the opening day predicted trips.
- If the ratio is less than 0.9995 or greater than 1.0005 then:
  - Take half the difference between the new predicted trips and the opening day predicted trips and add it to the opening day predicted trips.
  - Assign the new demands to the facility sections.
  - Reapply the HCM analysis to the new predicted demands.

- Compute new segment mean travel times and 80th percentile travel times.
- Compute new OD travel times (repeat Step 9.3) and recompute new demand (Step 9.4).
- Compare new OD trips to previous iteration estimated of OD trips.
- Stop iterations when ratios of latest iteration to previous iteration trips for each cell of OD tables is within 5 one-hundredths of one percent of 1.00.

Step 12: Compute MOEs (Equilibrated)

Assess Long-Term Performance

The "Long-Term" performance is computed for each scenario using the same procedures as were used for the "before" case.

Adjustments for Congestion Spill Over

In cases where the estimated queues spill over the temporal and/or spatial limits of the operations analysis tool then the best solution is to expand the limits of the tool and rerun the analysis. The limits should be revised if the spillover is frequent, occurring in many scenarios with cumulative probability of greater than 10%.

However, if the cumulative probability of those scenarios with spillovers is less than 10%, then the analyst may consider whether resource constraints, the low probabilities of such extreme scenarios, and cost-effectiveness considerations, may limit the ability to expand the limits. In such situations, it is necessary for the analyst to work with the study stakeholders to:

1. Assess the probability (and therefore the significance) of the scenarios causing the overflow,
2. Assess the degree to which not accurately modeling the overflows will introduce bias that would significantly affect the decisions regarding ATDM investments, and, if significant,
    a. Determine if a reasonable increase in the study limits will adequately capture the overflows, and if not,
    b. Approximately account for the congestion spill over outside of the operations analysis tool limits. Use the methodology described in Section 5.4 (Step 4).

If the decision is made at this late stage in the process that the study limits must be revised, then the "before" and "opening day" analyses will have to be repeated with the new limits so as to produce results comparable with the revised "long-term" analysis study limits.

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