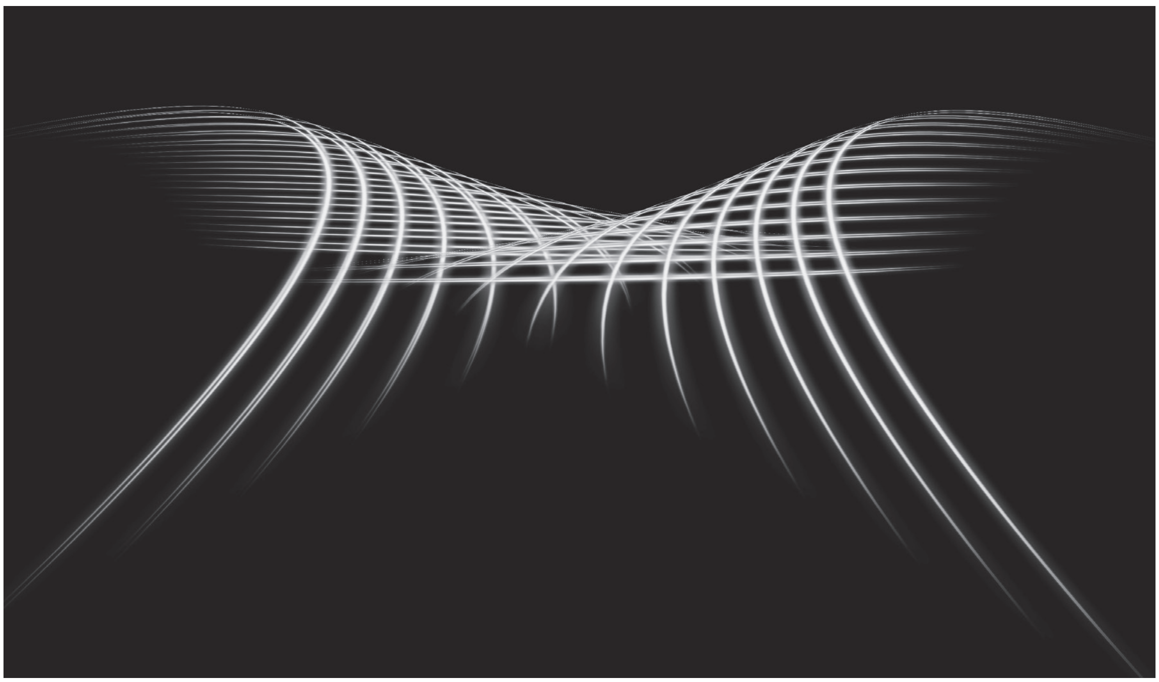
HCM2010

HIGHWAY CAPACITY MANUAL



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CHAPTER 35
ACTIVE TRAFFIC AND DEMAND MANAGEMENT

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

Active traffic and demand management (ATDM) is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of 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. Through the use of archived data and 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 chapter provides a conceptual analysis framework, recommended measures of effectiveness (MOEs), and an initial set of recommended methodologies for evaluating the impacts of ATDM strategies on highway and street system demand, capacity, and performance. Although the chapter describes various ATDM "strategies" and "measures," almost any system management or operations strategy that is applied in a dynamic manner can be considered active management.

The methodologies presented here are primarily focused on traffic management applications. They should be viewed as an initial, foundational set of methodologies. In some cases, the operational strategies presented here may be relatively static (e.g., fixed ramp-metering rates or pricing schedules). However, it is necessary to present them as the starting points in analyzing the benefits of applying more aggressive and dynamic treatments. In addition, there are several gaps in 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 chapter will provide the framework for the research that will fill those gaps.

The chapter presents practitioners with practical, cost-effective methods for representing the varied demand and capacity conditions that facilities may be expected to operate under and with methods for applying a realistic set of transportation management actions to respond to those conditions and thus representing, in a macroscopic sense, the dynamic aspects of ATDM. This chapter is designed to be used in conjunction with the freeway facility analysis chapter of the *Highway Capacity Manual* (HCM) for the planning, programming, and design of ATDM measures.

Although this chapter is intended to support ATDM analysis, several aspects of the methodology can be applied in analyzing non-ATDM-type alternatives. Highway capacity analyses are usually performed for near-ideal conditions, clear weather, no incidents, and recurring peak demand conditions. Evaluating highway performance under different demand, weather, incident, and work zone scenarios can provide a better understanding of facility performance under varying conditions.

PURPOSE

This chapter is intended to provide recommended methodologies and MOEs for evaluating the impacts of ATDM strategy investments on highway and street system demand, capacity, and performance.

ORGANIZATION

This chapter is organized as follows:

- *Introduction*—Describes the chapter's scope, purpose, limitations, and organization.
- *ATDM strategies*—Provides a brief overview of active transportation and demand management strategies.
- *Measures of effectiveness*—Presents recommended MOEs that build on traditional HCM measures for assessing the effectiveness of ATDM strategies.
- *Methodology*—Describes the methodology to be used in estimating the performance effects of ATDM investments.
- *Example applications*—Provides example applications of the methodology in the development of an ATDM investment plan for a freeway facility.
- *Appendices*—Provide supporting information for the chapter.

SCOPE AND LIMITATIONS

This chapter presents a conceptual framework and a specific methodology for using conventional HCM analysis methods in predicting facility capacity and the performance effects of various ATDM investments.

Since ATDM is further advanced on freeways than on urban streets, the chapter focuses on the analysis of freeway facilities, although, in principle, the same analysis framework can be applied to urban streets. As research results are obtained pertaining to urban streets, they can be used to expand the state of the practice to those facilities as well.

The ATDM analysis framework translates real-time dynamic control systems into their HCM-equivalent average capacities and speeds for 15-min analysis periods, the smallest unit of time measurement supported by the HCM. Thus, some of the more dynamic aspects of ATDM must be approximated in this chapter.

ATDM is about controlling demand as well as capacity; however, consistent with the rest of the HCM, this chapter focuses on the capacity side of ATDM. Demand is an input to these procedures that the analyst must determine by using other tools. Demand variability is considered where it influences total demand for the facility (such as peaking within the peak period and variations between days of the year). Demand changes are also considered in the methodology described in this chapter where they are the result of direct controls imposed on the facility, such as ramp metering and vehicle type restrictions [for example, high-occupancy vehicle (HOV) lanes or peak period truck bans]. However, prediction of how much additional traffic might be attracted to the facility with the improved performance resulting from ATDM (sometimes called "induced demand") is not included in the chapter's methodology.

INTRODUCTION TO ATDM STRATEGIES

This section provides brief overviews of typical ATDM strategies for managing demand, capacity, and the performance of the highway and street system. The appendices to this chapter and the FHWA ATDM website may be consulted for more details on ATDM strategies.

http://www.ops.fhwa.dot.gov/atdm

ATDM strategies are evolving as technology advances. The strategies described in this chapter represent the first effort at identifying the menu of ATDM strategies available to the analyst.

ATDM strategy categories:
- *Roadway metering*
- *Congestion pricing*
- *Traveler information*
- *Managed lanes*
- *Speed harmonization*
- *Signal timing*

Typical ATDM strategies can be classified according to their purpose and the manner in which they are applied:

- *Roadway-metering strategies* seek to store surges in demand at the entry points to the facility. Typical examples of roadway metering include freeway on-ramp metering, freeway-to-freeway ramp metering, freeway mainline metering, peak period freeway ramp closures, and arterial signal metering.
- *Congestion* or *value pricing strategies* seek to smooth out demand, improve reliability, and take advantage of unused capacity through pricing. These strategies involve charging tolls for use of all or part of a facility [such as a single express or high-occupancy toll (HOT) lane] according to the severity of congestion. The objective of congestion pricing is to preserve reliable operating speeds on the tolled facility with a tolling system that encourages drivers to switch to other times of the day, other modes, or other facilities when demand starts to approach facility capacity.
- *Traveler information strategies* (TIS) are an integration of technologies to provide the general public with better advance information on incident conditions, travel time, speed, and possibly other conditions. The intent of TIS is to enable drivers to make better-informed choices concerning travel routes, times, and modes.
- *Managed-lane strategies* include reversible lanes, HOV lanes, HOT lanes, truck lanes, speed harmonization, temporary closures for incidents or maintenance, and temporary use of shoulders during peak periods. These strategies seek to make more efficient use of available facility capacity.
- *Speed harmonization strategies* (such as variable speed limits) seek to improve safety and facility operations by reducing the shock waves that typically occur when traffic abruptly slows upstream of a bottleneck or for an incident. The reduction of shock waves reduces the probability of secondary incidents and the loss of capacity associated with incident-related and recurring traffic congestion.

- *Signal timing optimization and coordination strategies* minimize the stops, delay, and queues for vehicles at individual and multiple signalized intersections.

Specialized ATDM programs may be designed to address certain situations. For example, a *weather traffic management plan* may be developed to apply ATDM strategies during adverse weather events. A *traffic incident management plan* may apply ATDM strategies specifically tailored to incidents. A *work zone maintenance-of-traffic plan* may apply ATDM strategies tailored to work zones. *Employer-based demand management plans* may apply major employer–related ATDM strategies to address recurring congestion as well as special weather and incident events.

2. MEASURES OF EFFECTIVENESS FOR ATDM

INTRODUCTION

ATDM MOEs must be able to measure not only improvements in average performance but also improvements in the variability or reliability of that performance.

ATDM 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 forecast condition. Conventional performance measures and methodologies are inadequate for demonstrating the benefits of the dynamic and continuous monitoring and control of the transportation system provided by ATDM. ATDM MOEs must be able to measure not only improvements in average performance but also 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 MOEs for ATDM must be at the complete facility or system level. Consequently, MOEs that are typically used for system-level analysis are recommended for evaluating ATDM measures.

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.

BASIC PERFORMANCE MEASURES

The recommended basic performance measures are vehicle miles of travel (VMT) demanded, VMT served, vehicle hours traveled (VHT), and vehicle hours of delay (VHD). From these basic performance measures, several MOEs can be constructed.

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

VMT demanded is the sum of the products of the input origin–destination table vehicle trips and the shortest-path distance between each origin and destination. Although demand is not traditionally a performance measure for highway improvement projects, it is a measure of the success of ATDM in managing the demand for the facility.

VMT served is the sum of the products of the total link volumes for the peak period and the link lengths. VMT served is a measure of the productivity of the facility, the improvement of which is one of the key objectives of ATDM.

- VMT demanded and VMT served are ATDM performance measures in their own right. However, the difference between the two can be useful in determining whether the analyst has selected the appropriate study area and study time for evaluation. For each scenario, VMT demanded should be equal or nearly equal to VMT served. This indicates that the analyst successfully selected a study area and peak period capable of clearing all demand for each of the scenarios.

- If VMT demanded is greater than VMT served for any scenario, the analyst may need to expand the study period or make a manual adjustment to the reported results to account for the unserved demand.
- An excess of VMT served over VMT demanded indicates that congestion caused traffic to take longer routes to get around the bottlenecks. This can only occur in the evaluation of a system of facilities where multiple routes to the same destination are possible. When VMT demanded is less than VMT served, the ratio of VMT demanded to VMT served is a percentage indication of system inefficiencies caused by congestion.

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 during each time slice (either by controls, such as ramp metering, or by congestion) are added to and included in the reported VHT total.

VHD is the difference between 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 in each time splice, 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.

Agencies may elect to exclude the difference between the free-flow speed and the speed at capacity from the delay. VHD then becomes the time spent in queuing.

Agencies may elect to exclude the difference between the free-flow speed and the speed at capacity from the delay. VHD then becomes the time spent in queuing.

MEASURES OF EFFECTIVENESS

Four MOEs are recommended for evaluating the achievement of one or more ATDM objectives. They measure system productivity, system efficiency, personal perceptions of delays, and reliability. They are, respectively, the person miles traveled (PMT), the average system speed, the system VHD per vehicle trip, and the planning time index (PTI). The measures are computed across all of the scenarios to obtain overall results.

- PMT is a measure of the productivity of the highway system in terms of the number of people moved by the system and the number of miles they are moved. The total PMT is computed by multiplying the PMT served for each scenario by the probability of the scenario and then summing across all scenarios.
- *Average system speed* is a measure of the efficiency of the highway system. It is computed by summing 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, that is, to serve 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 in improving efficiency.

- The *average delay per mile* traveled is useful for conveying the results in a manner that can be related to personal experience. The average delay is measured in terms of *vehicle seconds of delay* divided by VMT. It is computed as the VHD summed over all of the scenarios divided by the sum of the VMT for all of the scenarios, with the result multiplied by 3,600 seconds per hour.
- PTI is a measure of the reliability of travel times on the facility. It is the ratio of the 95th percentile highest predicted travel time to the free-flow travel time. For example, a PTI of 1.20 means that travelers must allow 20% more than the free-flow travel time to get to their destinations on time with a 95% level of confidence.

3. METHODOLOGY

INTRODUCTION

The ATDM analysis framework (Exhibit 35-1) 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:

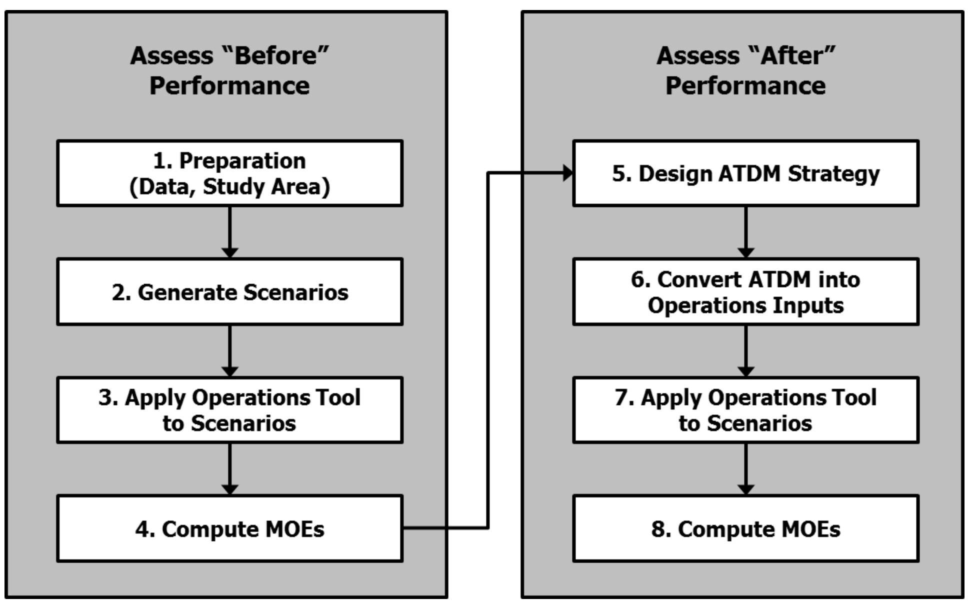
- Before implementation of the ATDM strategy and
- On opening day of implementation of the ATDM strategy.

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.

Opening day conditions predict how facility throughput, mean travel times, and travel time reliability will change after implementation of the ATDM strategy but before travelers are able to adjust their behavior in response to facility travel time and reliability changes. These conditions are roughly equivalent to what would be experienced on the first day of ATDM activation.

Post–opening day conditions may become important if the new facility travel times and reliability are significantly different from the "before" condition. An FHWA publication (*1*) may be consulted for advice on how to equilibrate the forecast demands for the facility after ATDM is implemented.

Exhibit 35-1
ATDM Analysis Flowchart



"BEFORE" ATDM PERFORMANCE 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 section presents the recommended preparatory steps for applying the procedures for estimating the effect of ATDM strategies on travel time reliability and person throughput for a single facility.

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

- Establishment of ATDM analysis purpose, scope, and approach and
- Data acquisition and processing.

Establish Purpose, Scope, and Approach for ATDM Analysis

The purpose, scope, and approach for the ATDM analysis are established at the start. The agency's goals for ATDM operation are identified. MOEs are selected for measuring achievement of the agency's goals. Thresholds of acceptability are determined to help guide the selection of ATDM improvement alternatives and investment levels. The range of ATDM investment strategies to be evaluated are identified. The scope of the analysis and the analysis approach are selected.

Agencies' goals for ATDM may include increased productivity, reduced delay, increased reliability, and improved safety.

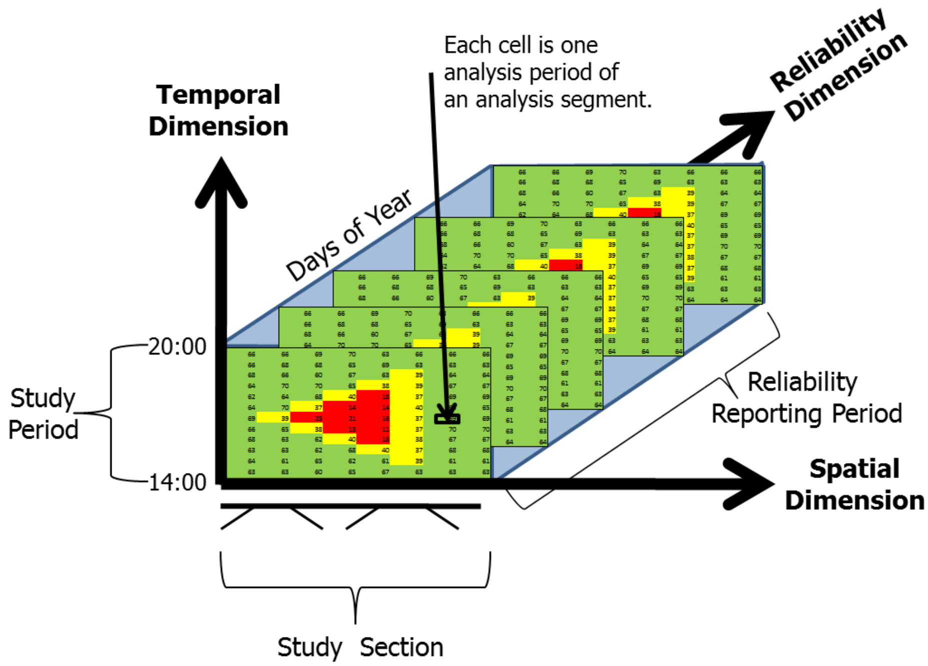
Geographic and Temporal Scope of Analysis

The ATDM analysis framework is designed to be applied to 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. Exhibit 35-2 provides definitions of key terms used in this section.

Exhibit 35-2
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. See also Exhibit 35-3.
Study period	The selected time period within the day for the operations analysis (e.g., a.m. 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. See also Exhibit 35-3.
Analysis period	The smallest subdivision of time used by the selected operations analysis tool (for example, if the HCM is used, the analysis periods are 15 min long).
Study section	If a single facility is to be evaluated, the study section is the length of the facility to be evaluated with the selected operations analysis tool. If a network of facilities is to be evaluated, the study section is the portion of the entire network to be evaluated with the selected operations analysis tool. See also Exhibit 35-3.
Analysis sections	Geographic subdivisions of the study section that are used by the operations analysis tool to evaluate performance.

Exhibit 35-3
Study Section, Study Period, and Reliability Reporting Period



The ATDM HCM 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.

Because it is often not feasible to evaluate such large study sections and periods to cover all eventualities, 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 year (the reliability reporting period). 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 on by the stakeholders in the analysis, and the reasons for the decision should be documented.

Required Inputs

The data required for a "before ATDM" analysis are identical to those needed for a reliability analysis. Chapters 36 and 37 provide details on performing reliability analyses.

The following are the minimum required input data for an ATDM analysis:

- Sufficient historical demand data and special event data to predict the variability of demand;
- Sufficient historical incident, work zone, and weather data to predict the variability of capacity; and
- Data required to perform a conventional HCM analysis of the facility.

The amount of processing required to make the available data suitable for ATDM analysis will depend on their quality and level of detail.

Acquisition and Processing of Demand Variability Data

Sufficient demand data must be gathered for the study period for a conventional HCM analysis of the facility. The HCM requires 15-min demands throughout the peak period, which might be based on a single day's data or 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 to be confident that a close approximation of the true variability of demands for the study period has been achieved.

Acquisition and Processing of Special Event Data

For most facilities, special events with a significant effect on facility operation are sufficiently rare that a separate special event analysis is unnecessary. Special events can be bundled into the overall demand variability data without requiring separate consideration in the ATDM analysis.

Separate consideration of special events may be warranted for facilities where they are a significant and frequent influence on facility operation. This is especially true if the agency is evaluating ATDM investments specifically designed to address major events. Major sporting events, 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, 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 (e.g., cones, directional signs, stationing of traffic control officers, parking lot controls) will need to be defined by the analyst in sufficient detail to allow this information to be translated into inputs to the HCM analysis tool.

Acquisition and Processing of Weather Data

Hourly weather reports published by the National Oceanic and Atmospheric Administration, Weather Underground, agency road weather information systems, and other sources can be used to estimate the frequency of weather types for the facility. For purposes of the reliability analysis, the weather data must specify the historical 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 of these metrics for almost every town and city in the United States.

The weather data must be classified into the appropriate HCM weather type category (which is different for freeways and urban streets). After the weather observations are classified, the probabilities of weather occurrence for each weather type can be computed. In 1 year, there should be 8,760 (365 × 24) hourly observations. The probability of occurrence of a weather type is the ratio of the number of observations of that type to 8,760. The annual hours per year of weather by type are used to compute the percentage frequencies.

If the prevalence of certain weather types regularly varies between the morning and evening peak periods (for example, afternoon thundershowers), the analyst should compile weather data only for the hours of the day representative of the selected study period (e.g., a.m. or p.m. peak period) for the analysis.

When multiple weather types are present at the same time in the data, the analyst should classify the weather type as being the one with the worst effect on capacity. Use the capacity adjustment factors in Exhibit 35-4 to identify which weather type has the worst effect. The lower the factor, the worse its effect on capacity.

Exhibit 35-4
Required Weather Data for ATDM Analysis

Weather Type	Range	Speed Adjustment Factor	Capacity Adjustment Factor	Illustrative Probability (%)
Clear	N/A	1.00	1.00	50.0
Light rain	>0.00–0.10 in./h	0.98	0.98	8.0
Medium rain	>0.10–0.25 in./h	0.94	0.93	4.0
Heavy rain	>0.25 in./h	0.93	0.86	2.0
Very light snow	>0.00–0.05 in./h	0.89	0.96	6.0
Light snow	>0.05–0.10 in./h	0.88	0.91	3.0
Medium snow	>0.10–0.50 in./h	0.86	0.89	2.0
Heavy snow	>0.50 in./h	0.85	0.76	2.0
Low wind	>10.00–20.00 mi/h	0.99	0.99	4.0
High wind	>20.00 mi/h	0.98	0.98	2.0
Cool	34°F–49.9°F	0.99	0.99	2.0
Cold	-4°F–33.9°F	0.98	0.98	2.0
Very cold	<-4°F	0.94	0.91	3.0
Medium visibility	0.50–0.99 mi	0.94	0.90	2.0
Low visibility	0.25–0.49 mi	0.93	0.88	2.0
Very low visibility	<0.25 mi	0.93	0.88	6.0

Note: N/A = not applicable.

Note that the set of default weather-related speed and capacity adjustment factors for ATDM analysis is slightly different from that provided for reliability analysis in Chapter 36. Both sets of defaults are within the range of observed values, and either can be used.

The minimum required weather data consist of the probability of occurrence during the reliability reporting period for each weather type. The speed and capacity adjustment factors in Exhibit 35-4 can be used as defaults if local data are lacking. These factors are designed to be applied to the capacity or free-flow speed for the facility computed under the HCM methods described in Volume 2 for freeway facilities. See Appendix B for the derivation of the capacity and speed adjustment factors shown here. Probabilities given in Exhibit 35-4 are illustrative and are not intended to represent actual conditions anywhere.

Acquisition and Processing of Incident Data

The ATDM HCM analysis method requires the incident data identified in Exhibit 35-5: 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 1 year).

Exhibit 35-5
Incident Data Required for ATDM Analysis

Incident Type	Maximum Lanes Blocked	Mean Duration (min)	Free-Flow Speed Adjustment Factor	Capacity Adjustment Factor	Illustrative Probability (%)
None	None	N/A	1.00	1.00	37.53
Noncrash incidents	Shoulder	30	1.00	0.99	43.42
	1	30	1.00	0.79	7.66
	2+	45	1.00	0.61	0.80
Property damage only crashes	Shoulder	30	1.00	0.86	4.90
	1	45	1.00	0.79	2.44
	2+	60	1.00	0.61	1.44
Injury crashes	Shoulder	60	1.00	0.86	0.99
	1	60	1.00	0.79	0.49
	2+	60	1.00	0.61	0.29
Fatal crashes	Shoulder	180	1.00	0.86	0.02
	1	180	1.00	0.79	0.01
	2+	180	1.00	0.61	0.01
Total					100.00

Note: N/A = not applicable.

Note that the set of default incident-related capacity adjustment factors for ATDM analysis is different from that provided for reliability analysis in Chapter 36. Both sets of defaults are within the range of observed values, and either can be used.

The analysis will be most accurate if archived incident data are available for the facility in the requisite detail. In their absence, the required data can be estimated for existing conditions or forecast for future conditions by using *Highway Safety Manual* (*2*) procedures or the defaults described in Appendix C. The effects of incidents on free-flow speeds and capacities of the remaining open lanes can be estimated by using the defaults described in Appendix B.

See Appendix C for the derivation of mean incident duration and probabilities. These factors are designed to be applied to the capacity or free-flow speed for the facility computed under the HCM methods described in Volume 2 for freeway facilities. See Appendix B for the derivation of the capacity and speed adjustment factors shown here. Probabilities shown in Exhibit 35-5 are illustrative and are not intended to represent actual conditions anywhere.

Note that the set of default work zone–related capacity adjustment factors for ATDM analysis is slightly different from that provided for reliability analysis in Chapter 36. Both sets of defaults are within the range of observed values, and either can be used.

Work Zone Data

If work zones are anticipated to affect annual traffic operations (or the ATDM investments to be tested are anticipated to improve work zone traffic operations significantly), the analyst should identify the general frequencies of work zone by type, duration, usual posted speed limits, and number of lanes to remain open (see Exhibit 35-6).

Exhibit 35-6
Work Zone Data Required for "Before" ATDM Analysis

Type	Lanes Open	Illustrative Duration (min)	Capacity (veh/h/ln)	Speed Adjustment Factor	Illustrative Probability (%)
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

Notes: N/A = not applicable.
Durations reflect the number of minutes within the study period that the work zone is active.

The probabilities in Exhibit 35-6 are illustrative and are not representative of real-world conditions. The speed adjustment factors and per lane capacities in this table can be used as defaults if local data are lacking.

These speed factors are designed to be applied to the free-flow speed for the facility computed under the HCM methods described in Volume 2 for freeway facilities. The capacity values are designed to be applied as described in Chapter 10 for Exhibit 10-14.

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

Work zones in place more than 1 day are generally classified as "long-term" work zones. Long-term work zones generally have traffic control requirements different from those of short-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 work zone duration is the number of minutes within the study period during which the work zone is active.

Per lane work zone capacities are provided in Exhibit 35-6. The work zone capacity adjustment factors are calculated by comparing the work zone capacities with the capacity without any work zones.

Data Required for Conventional HCM Analysis

In addition to the above-described data, the data needed for a conventional HCM analysis of the facility are required. The general input requirements for freeway analysis are given in Chapter 10 and subsequent chapters within Volume 2. For an arterial street analysis, the input requirements are given in Chapter 16 and subsequent chapters within Volume 3.

Step 2: Generate Scenarios

Highway capacity analyses are usually performed for near-ideal conditions, such as clear weather, no incidents, and recurring peak demand conditions. ATDM is designed to respond to nonideal conditions. Thus, scenarios of nonideal conditions must be created to evaluate the benefits of ATDM.

Because of the number of scenarios that need to be evaluated, the methodology assumes that the analyst has access to an operational analysis tool that implements the HCM freeway or urban streets methodology, depending on the type of facility being analyzed.

The computational and human resources required to generate inputs, compute performance, check for errors, and evaluate the results for each scenario set practical limits on the number of scenarios that can be considered for any given ATDM investment analysis. Therefore, the objective of scenario generation is to identify a sufficient number of varied, representative scenarios to evaluate accurately the benefits of the ATDM investments under consideration, without exceeding the analyst's resources.

As more sophisticated computational tools become available, the number of scenarios that can be evaluated will be less constrained by resources.

The ATDM analysis method starts by generating the full range of possible scenarios and then strategically selects 30 scenarios for HCM analysis. This procedure allows rapid analysis of the effects of ATDM strategies on facility performance.

The analysis framework provides for up to

- Seven demand levels,
- 16 weather subscenarios,
- 13 incident subscenarios, and
- Seven work zone subscenarios.

The available demand, weather, incident, and work zone subscenarios combine to form 10,192 possible scenarios for analysis. Since generation of ATDM responses for and evaluation of this many scenarios are not feasible with available tools, the analyst must select 30 for analysis.

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

The "before ATDM" method described here is similar to the freeway reliability method described in Chapters 36 and 37. The month-of-year and day-of-week approach to demand variability used for reliability analysis has been condensed to seven demand levels here so that the ATDM analysis can be applied to fewer scenarios than the reliability method uses.

Fewer scenarios for ATDM analysis than for reliability analysis are recommended. This is because for ATDM, each scenario must be analyzed twice (once for "before" and again for "after"). In addition, the analyst must specify an ATDM response for each scenario. Thus, for pragmatic reasons, an ATDM analysis uses fewer scenarios than does the reliability analysis method.

Identify and Describe Demand Levels

The analyst identifies seven 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 historical or estimated historical demand data. Such data may come from nearby permanent count stations. The total study (peak) period demands for each day in the archive are ranked from lowest to highest. The 5th-, 15th-, 30th-, 50th-, 70th-, 85th-, and 95th-highest percentile values are then selected.

Usually, the demand data requirements for coding the traffic analysis tool are much more detailed than the data available in the archives. Consequently, it is usually necessary to collect the more detailed data for HCM analysis for a single day (the seed day) and then factor those single-day demands to the target percentile demand level. The HCM analysis input seed-day demands are compared with the target demand levels and factored up or down as necessary to match the target demand level. Unless the analyst has better data, 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 5th percentile demand is assumed to be representative of the bottom 10% of demands. The 15th percentile demand is representative of demands between the 10th percentile and the 20th percentile and thus has an estimated 10% probability, and so on. These ranges divide the travel time range into roughly equal-length segments between the 5th and 95th percentile levels, as illustrated in Exhibit 35-7.

Exhibit 35-7
Assignment of Probabilities to Percentile Demand Levels

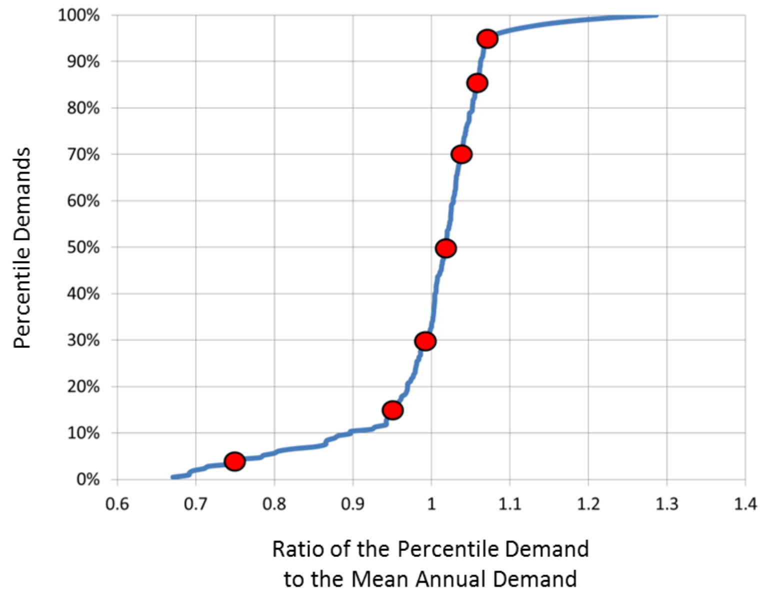


Exhibit 35-8 shows an example outcome for this step. Seven demand levels have been selected from the facility's demand profile. For each level, a probability has been estimated, along with an adjustment factor to be applied to the demands in the HCM seed file to create the demand level.

Exhibit 35-8
Example Output of Demand Level Selection Step

Demand Level	Probability (%)	Ratio of Percentile Demand to Annual 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

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. This example also assumes that special events have been subsumed within the demand levels selected for analysis. Therefore, no separate special event demand levels are generated.

Define Weather Subscenarios

The ATDM analysis method uses the freeway weather types identified in Chapter 10, Freeway Facilities. The available weather subscenarios were given in Exhibit 35-4. 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 Subscenarios

The ATDM analysis method uses the freeway incident types identified in Chapter 10, Freeway Facilities. The available incident subscenarios were given in Exhibit 35-5. 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, study period, and reliability reporting period, evaluation of all of these possibilities within 30 scenarios is not feasible. 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 a location for the incident near the downstream end of the study section and a start time near the start of the study period.

Define Work Zone Subscenarios

The ATDM analysis method uses the freeway work zone types identified in Chapter 10, Freeway Facilities. The available work zone subscenarios were given in Exhibit 35-6. A total of seven types are available, including no work zone; short-term work zones keeping one, two, or three lanes open; and long-term work zones keeping one, two, or three lanes open.

The ATDM analysis method is indifferent to the name of the work zone type (i.e., long-term versus short-term). 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 framework.

While work zones can occur at any time and location within the study section, study period, and reliability reporting period, evaluation of all of these possibilities within 30 scenarios is not feasible. 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 and Computation of Probabilities

The seven demand levels, 16 weather subscenarios, 13 incident subscenarios, and seven work zone subscenarios are combined in all possible ways. The result is 10,192 possible scenarios for analysis.

The analyst inputs the individual probabilities for each of the demand levels and subscenarios of weather, incidents, and work zones. These marginal probabilities are used to compute the combined probability of each scenario; independence of subscenarios and demand levels is assumed.

Equation 35-1

$$P(d, w, i, wz) = P(d) \times P(w) \times P(i) \times P(wz)$$

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); and

$P(wz)$ = probability of work zone type wz (analyst input).

The assumption that demand, weather, incidents, and work zones are independent is not statistically correct, but it produces reasonable first-order approximations of the relative joint probabilities of the various combinations of events.

Selection of 30 Scenarios for HCM Analysis

At this point in the process, the seven demand levels, 16 weather subscenarios, 13 incident subscenarios, and seven work zone subscenarios have generated 10,192 possible scenarios for analysis. The analyst must select 30 of them.

The need to reduce the analysis from 10,192 scenarios to 30 is driven by the amount of effort required to specify fully the ATDM strategies to be used individually for each scenario. At this early stage of ATDM development in the United States, the analyst must have complete freedom to specify the ATDM strategies for each scenario. This freedom requires more effort on the part of the analyst. 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 analyst explicitly selects the combination of subscenarios to be used in each scenario. Exhibit 35-9 illustrates one possible outcome under this method of scenario selection.

Step 3: Apply Operations Model to Scenarios

In this step the selected HCM operations analysis model is coded, checked for errors, and calibrated, as appropriate.

The conventional HCM analysis 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 HCM analysis to reflect those events.

It is critical that the seed file be accurate and as error-free as possible, because the entire ATDM evaluation will pivot off of the seed file.

It is critical that the seed file (the conventional HCM analysis input file) be accurate and as error-free as possible, because the entire ATDM evaluation will pivot off of the seed file.

Exhibit 35-9
Example Scenario Selection

Scenario No.	Demand	Weather	Incident	Work Zone	Probability (%)
1	Low	Clear	None	None	14.25
2	Low	Clear	None	Long-term 1	1.02
3	Low	Clear	PDO-1	None	1.14
4	Low	Clear	PDO-1	Long-term 1	0.08
5	Low	Medium rain	None	None	1.14
6	Low	Medium rain	None	Long-term 1	0.08
7	Low	Medium rain	PDO-1	None	0.09
8	Low	Medium rain	PDO-1	Long-term 1	0.01
9	Low	Light snow	None	None	0.86
10	Low	Light snow	None	Long-term 1	0.06
11	Medium	Clear	PDO-1	None	3.99
12	Medium	Clear	PDO-1	Long-term 1	0.29
13	Medium	Clear	None	None	49.89
14	Medium	Clear	None	Long-term 1	3.56
15	Medium	Medium rain	PDO-1	None	0.32
16	Medium	Medium rain	PDO-1	Long-term 1	0.02
17	Medium	Medium rain	None	None	3.99
18	Medium	Medium rain	None	Long-term 1	0.29
19	Medium	Light snow	PDO-1	None	0.24
20	Medium	Light snow	PDO-1	Long-term 1	0.02
21	High	Clear	None	None	14.25
22	High	Clear	None	Long-term 1	1.02
23	High	Clear	PDO-1	None	1.14
24	High	Clear	PDO-1	Long-term 1	0.08
25	High	Medium rain	None	None	1.14
26	High	Medium rain	None	Long-term 1	0.08
27	High	Medium rain	PDO-1	None	0.09
28	High	Medium rain	PDO-1	Long-term 1	0.01
29	High	Light snow	None	None	0.86
30	High	Light snow	PDO-1	Long-term 1	0.00
				Total	100.00

Notes: PDO-1 = property-damage-only crash with one lane closed.
Long-term 1 = long-term work zone with one lane closed.

Step 4: Compute the "Before" ATDM MOEs

The MOEs reported by the operations analysis tool for each scenario are combined to obtain the total performance statistics for the facility or facilities.

The performance measures and MOEs reported for the "before" condition are listed below.

- Basic performance measures useful for computing MOEs:
  - VMT demanded
  - VMT served
  - VHT
  - VHD
- MOEs:
  - System efficiency: average system speed
  - Traveler perspective: VHD/VMT
  - Reliability: PTI

Exhibit 35-10 shows a typical table of MOEs computed for a "before" ATDM analysis. The summary statistics are computed from the values in this table, with the results shown in Exhibit 35-11.

Exhibit 35-10
Example MOE Output (Partial Listing)

Scenario Number	Scenario Probability (%)	VMT Demanded	VMT Served	VHD	VHT	Maximum *d/c* Ratio	Max. Travel Time (min)	Mean TTI	Mean Speed (mi/h)	Min. Speed (mi/h)	Max. Queue (mi)	% Analysis Periods 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	86,794	86,794	85	1,325	0.88	7.0	1.1	65.5	64.3	0.00	0.0
4	1.1	86,794	86,794	262	1,502	1.70	26.5	1.4	57.8	26.9	1.14	18.8
5	4.3	86,794	86,794	199	1,439	0.95	7.8	1.1	60.3	58.1	1.14	6.3
6	17.2	86,794	86,794	216	1,456	0.95	7.9	1.2	59.6	57.4	1.14	6.3
7	8.6	86,794	86,794	200	1,440	0.95	7.8	1.2	60.3	58.1	1.14	6.3
8	0.1	86,794	86,794	410	1,650	1.82	30.9	1.5	52.6	24.1	1.25	25.0
9	5.7	86,794	86,794	293	1,533	0.97	8.3	1.2	56.6	54.6	1.25	6.3
10	10.2	86,794	86,794	311	1,550	0.97	8.4	1.2	56.0	54.0	1.25	6.3
11	0.0	93,327	93,327	95	1,427	0.95	7.1	1.1	65.4	63.8	1.25	0.0
12	8.6	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	93,327	93,327	256	1,587	1.02	8.6	1.2	58.8	51.8	0.51	12.5

Notes: Only the first 15 scenarios are shown.
This exhibit shows some results to more digits than are significant.
VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; Max. = maximum; Min. = minimum; TTI = travel time index.

Exhibit 35-11
Example Summary Statistics for "Before" ATDM Condition

MOE	Value	Units
VMT demanded	22,433,669	Annual veh-mi
VMT served	22,433,669	Annual veh-mi
VHT	386,024	Annual veh-h
VHD	65,905	Annual veh-h
Average speed	58.11	mi/h
Average delay	10.58	s/mi
PTI (95th percentile TTI)	1.69	None

Notes: This exhibit shows some results to more digits than are significant.
VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index; TTI = travel time index.

The VMT demanded is the same as the VMT served, 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 mi/h (about 83% of the 70-mi/h free-flow speed for the facility). The average delay is 10.6 s/mi. The PTI (95th percentile TTI) is 1.69: in other words, to be 95% confident of arriving on time over the course of a year of weekday p.m. peak periods, travelers must add 69% to their expected free-flow travel time on the facility.

"AFTER" ATDM PERFORMANCE ANALYSIS

The second phase of an ATDM investment analysis is the "after" analysis. This phase estimates the capacity and performance effects of ATDM investments for the facility.

Step 5: Design the ATDM Strategy

The state of the art for ATDM operations was evolving rapidly at the time of writing. 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 various general ATDM management approaches without requiring the analyst to evaluate and test every possible option and determine the optimal control settings for each real-life situation. Thus, this method is not suitable for determining the precise control settings that are optimal for a range of real-life conditions. The method is designed to determine the likely benefits of introducing the control flexibility and responsiveness of ATDM to a facility.

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

The ATDM analysis method is designed to address the following menu of ATDM strategies:

- Travel demand management (TDM) strategies,
- Weather traffic management plan (W-TMP),
- Traffic incident management (TIM) plan,
- Work zone traffic management plan (WZ-TMP),
- Variable speed limits (VSLs) (speed harmonization),
- HOV–HOT lane management strategies,
- Shoulder lane strategies,
- Median lane strategies,
- Truck controls, and
- Ramp metering.

The following are the 10 ATDM strategies available in the ATDM analysis method:

- *Travel demand management*
- *Weather traffic management*
- *Traffic incident management*
- *Work zone traffic management*
- *Variable speed limits*
- *HOV–HOT lane management*
- *Shoulder lane strategies*
- *Median lane strategies*
- *Truck controls*
- *Ramp metering*

TDM Strategies for Recurrent Congestion

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. 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.

TDM strategies to address recurrent congestion include congestion pricing strategies, traveler information strategies, and employer-based TDM.

- Congestion pricing may include specific lane tolling or full facility tolling.
- Travel information strategies include pretrip strategies (e.g., web-based information) and en route information (e.g., cell phones, in-vehicle navigation devices, changeable message signs).
- Employer-based TDM includes a wide range of employer incentives and disincentives to reduce single-occupant vehicle commuting before the vehicle reaches the 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 of the strategies on demand within each of the plans, as illustrated in Exhibit 35-12.

Exhibit 35-12
Illustrative Coding of TDM Plans for ATDM HCM Analysis

Demand Level	Description	TDM Plan Demand Adjustment Factor
1	Very low demand	0.98
2	Low demand	0.97
3	Low–medium demand	0.96
4	Medium demand	0.95
5	Medium–high demand	0.94
6	High demand	0.93
7	Very high demand	0.92

The analyst identifies the levels of demand at which each TDM plan goes into effect. Each TDM plan is assumed to affect facilitywide demand uniformly for the entire study period for the scenario when the plan is in force.

The analyst may specify a different TDM plan, with a different effect on demand, for each of the seven possible levels of demand identified by the analyst in the "before" analysis.

Entries shown in Exhibit 35-12 are illustrative of a hypothetical TDM plan that becomes more aggressive (by 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 that ATDM causes no change in the demand. Each row represents a different possible ATDM response for a different recurring demand condition.

Weather Traffic Management Plan

W-TMPs consist of control strategies, traveler advisory strategies, and treatment strategies.

- Control strategies restrict the vehicles and impose equipment requirements (such as chains) for vehicles using the facility during adverse weather.
- Traveler advisories include pretrip and en route information to advise drivers of weather conditions.
- 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 W-TMPs for the facility. The analyst estimates the combined effects of the strategies within each plan on facility demand, capacity, and free-flow speeds, as illustrated in Exhibit 35-13. The analyst identifies the weather types when each W-TMP goes into effect. Each W-TMP is assumed to affect the entire facility uniformly for the entire study period when the weather type is present and the W-TMP is in force.

The analyst may specify a different W-TMP, 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.

Exhibit 35-13
Illustrative Coding of W-TMPs for ATDM Analysis

Weather Type	Speed Adjustment	Capacity Adjustment	Demand Adjustment
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	1.00	1.00	1.00
Light snow	1.00	1.05	0.90
Medium snow	0.90	1.05	0.75
Heavy snow	0.80	1.05	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°F	1.00	1.00	1.00
Temperatures below -4°F	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

Entries in Exhibit 35-13 are illustrative of the coding capabilities and are not intended to represent actual W-TMP effects. A value of 1.00 means that ATDM will not change the effect of the weather. For example, if light snow reduces the capacity by 9% and ATDM increases the roadway's capacity under light snow conditions by 5%, the net effect on capacity is 0.91 × 1.05 or 0.96. 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 TIM plan consists of site management and control strategies; traveler advisory strategies; and detection, verification, response, and clearance strategies.

- Site management and traffic control strategies include incident command systems, on-site traffic management teams, and end-of-queue advance warning systems.
- Traveler advisory strategies include pretrip traveler information, portable message signs, changeable message signs, and employer-based TDM programs.
- Detection and verification strategies include field verification by on-site responders, closed-circuit television cameras, enhanced roadway reference markers, enhanced or automated 911 positioning systems, motorist aid call boxes, and automated collision notification systems.
- Response strategies include personnel and equipment resource lists, towing and recovery vehicle identification guides, instant tow dispatch procedures, towing and recovery zone-based contracts, enhanced computer-aided dispatch, dual or optimized dispatch procedures, motorcycle patrols, and equipment staging areas or pre-positioned equipment.
- Quick clearance and recovery strategies include incident investigation sites; quick clearance laws, policies, and incentives; expedited crash

investigations and service patrols and enhanced capability service patrols; and major incident response teams.

The various TIM 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 types of incidents that cause each TIM plan to go into effect.

Each TIM plan is assumed to affect demand uniformly for the entire facility for the analysis time periods when the incident is present and the TIM plan is in force. Capacity and free-flow speeds are assumed to be affected by the TIM plan only in the vicinity of the incident and while it is present. Variable speed limits (discussed in the next subsection) 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, as illustrated in Exhibit 35-14.

Exhibit 35-14
Illustrative Coding of TIM Plans for ATDM HCM Analysis

Incident Type	VSL Upstream?	Adjustment Factors: Duration	Speed	Capacity	Demand
No incident	No	1.00	1.00	1.00	1.00
Noncrash blocking shoulder	No	0.95	0.95	1.00	1.00
Noncrash blocking 1 lane	Yes	0.95	0.80	1.00	1.00
Noncrash blocking 2+ lanes	Yes	0.95	0.80	1.00	1.00
PDO crash on shoulder	No	0.90	0.95	1.00	1.00
PDO crash blocking 1 lane	Yes	0.90	0.80	1.00	1.00
PDO crash blocking 2+ lanes	Yes	0.90	0.80	1.00	0.95
Injury crash on shoulder	No	0.90	0.95	1.00	1.00
Injury crash blocking 1 lane	Yes	0.90	0.80	1.00	0.95
Injury crash blocking 2+ lanes	Yes	0.90	0.80	1.00	0.90
Fatal crash on shoulder	No	0.90	0.95	1.00	1.00
Fatal crash blocking 1 lane	Yes	0.90	0.80	1.00	0.90
Fatal crash blocking 2+ lanes	Yes	0.90	0.80	1.00	0.85

Notes: PDO = property damage only; VSL = variable speed limit.

Entries in Exhibit 35-14 are illustrative of the coding capabilities and are not intended to represent actual TIM effects. A value of 1.00 means that ATDM will not change the effect of the incident. For example, if an injury crash blocking one lane reduces the capacity of the remaining open lanes by 21% and ATDM increases the capacity of the remaining open lanes by 0%, then the net effect on capacity is 0.79 × 1.00 or 0.79. Each row in the table represents a different possible ATDM response for a different incident type.

Variable Speed Limits

VSLs may be applied in four ways in the ATDM HCM analysis framework:

- The analyst may specify uniform reductions in the facility free-flow speed for each of the seven available demand levels.
- The analyst may specify uniform reductions in the facility free-flow speed for each of the 16 possible weather types.

- 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.
- 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.

If a VSL strategy is used for a work zone or an incident, 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.

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

Work Zone Traffic Management Plan

The 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.
- Traveler advisory strategies include pretrip traveler information, changeable message signs, portable message signs, and employer-based TDM, among other strategies.

The various work zone traffic management strategies are bundled by the analyst into one or more WZ-TMPs 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 that bring each WZ-TMP into effect.

Each WZ-TMP is assumed to affect demand uniformly for the entire facility for the analysis time periods when the work zone is present and the WZ-TMP is in force. Capacity and free-flow speeds are assumed to be affected by the WZ-TMP only in the vicinity of the work zone and while it is present, as illustrated in Exhibit 35-15. Work zone–triggered VSLs 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, with different effects on demand, capacity, and free-flow speeds, for each of the seven possible work zone types identified by the analyst in the "before" analysis.

Entries in Exhibit 35-15 are illustrative of the coding capabilities and are not intended to represent actual WZ-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.

Exhibit 35-15 Illustrative Coding of WZ-TMPs

Work Zone Type	VSL Upstream?	Speed Adjustment	Capacity Adjustment	Demand Adjustment
No work zone	No	1.00	1.00	1.00
Short-term, 1 open lane	No	1.00	1.00	1.00
Short-term, 2 open lanes	No	1.00	1.00	1.00
Short-term, 3 open lanes	No	1.00	1.00	1.00
Long-term, 1 open lane	Yes	1.00	1.00	1.00
Long-term, 2 open lanes	Yes	1.00	1.00	1.00
Long-term, 3 open lanes	Yes	1.00	1.00	1.00

Note: VSL = variable speed limits.

HOV–HOT Lane Management Strategies

The ATDM HCM analysis framework is set up to evaluate five possible HOV and HOT lane management strategies in response to demand, weather, incidents, and work zones:

- No change to “before” conditions.
- Convert one or more mixed-flow lanes (coded in the seed file) to HOV lanes.

  This option reduces the capacity of the mixed-flow lane(s) to the user-specified value for the HOV lane(s), determined by using Chapter 38, Managed Lane Facilities. This value is compared with 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.
- Open the HOV lane(s) 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.
- Convert one or more mixed-flow lanes (coded in the seed file) to HOT lanes 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 capacity is reached, at which point the HOT lane capacity will control.
- Open the HOT lane(s) 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.

The freeway facility must be defined in such a way that managed lanes either are or are not present for the entire length of the facility. The analytical details for these options are given in Appendix E.

Shoulder and Median Lane Strategies

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

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

More analytical details on capacities and speeds for these options are provided in Appendix F.

Truck Controls

Two options are available for truck controls: "base" (no change from the seed file) and "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 passenger car equivalent value per truck is used along with the percentage of trucks to compute the capacity adjustment factor for the freeway. The user-specified truck percentage is used to compute the demand reduction factor (1 minus the truck percentage) to be applied to all facility demands. Since a gross vehicle weight limit may affect less than 100% of the trucks on the freeway, the truck percentage entered by the user for the truck ban can be less than or equal to the total percentage of trucks on the facility.

Since the HCM's freeway method does not yet have a procedure for estimating the effects of trucks on average free-flow speeds, the ATDM analysis procedure assumes that a truck ban will have no effect on facility free-flow speeds.

Ramp Metering

Three ramp metering strategies are provided in the ATDM HCM analysis framework, in addition to the "no change" option.

- No change to "before" conditions.
- Meters operate at fixed (potentially varying by time of day) rates during the study period.
- Meters operate in dynamic local optimal mode. Each ramp meter optimizes its own rate on the basis of freeway mainline volumes immediately upstream and downstream of the ramp.

  The methodology sets the meter rate for each 15-min 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).

- The "meter off" option turns off all on-ramp meters and resets the on-ramp capacities to the user-specified ramp capacity. The merge capacity is multiplied by the user-supplied factor to account for the impact of ramp volume microsurges on the freeway merge capacity.

Additional analytical details are provided in Appendix G.

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 in which multiple plans are in effect (for example, an incident in a work zone during bad weather), the effects are multiplied together (on the assumption of independent multiplicative effects), with the exception of the free-flow speed adjustment factor. 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 hypothetical adjustment of 0.50 occurring in a work zone with a hypothetical work zone speed adjustment of 0.75, the combined effect on free-flow speed is assumed to be the minimum of the two plans (0.50 in this case), and not the two factors multiplied together.

Step 7: Apply the Operations Analysis Tool (Opening Day)

This step involves coding the ATDM strategies into each of the conventional HCM operations analysis 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 by time slice within the scenario. The analyst may find it desirable to create a "control emulator" to automate the adjustments. The emulator reads the demands for each time slice within each demand and capacity scenario and applies the appropriate capacity and control adjustment.

In cases where the ATDM measure is expected to influence the frequency, severity, or duration of incidents, the probabilities of the capacity scenarios with incidents will need to be modified as well.

Step 8: Compute MOEs (Opening Day)

Assess Opening Day Performance

The opening day performance is computed for each scenario by using the same procedures as were used for the "before" case.

Adjustments for Congestion Spillover

In cases where the estimated queues spill over the temporal or spatial limits of the HCM operations analysis, the best solution is to expand the limits of the HCM analysis and rerun the analysis. The limits should be revised if spillover occurs frequently (i.e., occurs in many scenarios with a cumulative probability of greater than 10%).

If the cumulative probability of the scenarios with spillovers is less than 10%, the analyst may take into account resource constraints, the low probabilities of such extreme scenarios, and cost-effectiveness considerations in determining whether to expand the limits. In such situations, the analyst must work with the study stakeholders to

1. Assess the probability (and therefore the significance) of the scenarios causing the overflow and
2. Assess the degree to which failure to model the overflows accurately will introduce bias that would significantly affect decisions with regard to ATDM investments. If the effects are significant, determine whether a reasonable increase in the study limits will adequately capture the overflows. If they are not significant, account for the congestion spillover outside of the operations analysis tool's limits approximately through classical queuing analysis.

4. EXAMPLE PROBLEMS

INTRODUCTION

This section describes several example applications of the ATDM HCM analysis method to the estimation of annual facility performance.

The baseline ("before") ATDM conditions are established first. Three ATDM investment strategies are then tested: converting an HOV lane to HOT (with congestion pricing), installing dynamic ramp metering, and implementing a recurring congestion TDM program along with a targeted incident-based TDM program.

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

"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 experiences relatively little recurrent congestion, but it is operating close to the margin. Work zones, weather, and incidents can have significant effects on congestion. The leftmost lane is dedicated to HOV 2+ during weekday p.m. peak periods. The HOV lane is slightly underutilized, carrying at most 1,350 veh/h.

The agency wishes to determine whether ATDM strategies might be used to take advantage of the spare capacity in the HOV lane during weather, work zone, and incident events and thereby improve 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 an HCM-based analysis, because at this early investment decision-making stage, it is not necessary to identify specific ATDM operating parameters, 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-mi-long section of three-lane freeway in one direction with five on-ramps and four off-ramps, as shown schematically in Exhibit 35-16.

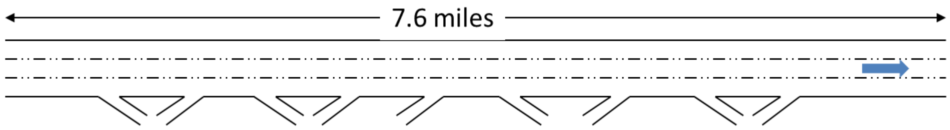


Exhibit 35-16
Example Application Study Site

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

Data Collection

Data are assembled for the selected study facility and time period for a traditional HCM freeway facility analysis. (These HCM data become the seed file for the reliability analysis and generation of scenarios.) Data are then assembled on the day-to-day variability of demand, the historical 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 FREEVAL-ATDM spreadsheet was selected as the core analysis tool. The required data are geometric details and 15-min ramp and mainline counts for the study period.

Exhibit 35-17 shows the geometric and demand data for the first 15-min analysis period within the selected 4-h study period for the first 10 segments of the facility. Exhibit 35-18 shows the same data for the remaining 10 segments.

The geometry and other parameters (such as percentage of trucks) are identical in this example for all analysis periods. Mainline and ramp demands increase by 10% in each analysis period after the first. Starting with the ninth analysis period, the mainline and ramp demands decrease by 10% from the previous analysis period.

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 with the seed file demands, and the adjustment factors and probabilities were obtained. The results are shown in Exhibit 35-19.

Weather Data

Weather data for the past 3 years were obtained for a nearby weather station. The data were aggregated into HCM weather types. Probabilities were computed for the weekday p.m. peak period. Capacity and free-flow speed adjustment factors were obtained from Exhibit 35-4. Demand was assumed to be unaffected by weather for this example problem. The resulting data are shown in Exhibit 35-20.

Exhibit 35-17
Seed File Input Data (Analysis Period No. 1, Segments 1–10)

Segment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Type	B	B	OFR	B	ONR	B	OFR	B	ONR	B
Length (ft)	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
Free-flow speed (mi/h)	70	70	70	70	70	70	70	70	70	70
Demand (veh/h)	2,700	2,700	2,700	2,500	2,700	2,700	2,700	2,500	2,700	2,700
Capacity adjustment	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
Destination demand adj.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Speed adj.	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
% recreational vehicles	0	0	0	0	0	0	0	0	0	0
On-ramp demand (veh/h)					200				200	
On-ramp % trucks					5.0				5.0	
On-ramp % recreational vehicles					0.0				0.0	
Off-ramp demand (veh/h)			200				200			
Off-ramp % trucks			5.0				5.0			
Off-ramp % recreational vehicles			0.0				0.0			
Acc./dec. lane length (ft)			300		300		300		300	
Lanes on ramp			1		1		1		1	
Ramp side			Right		Right		Right		Right	
Ramp free-flow speed (mi/h)			45		45		45		45	
Ramp meter rate (veh/h)					2,100				2,100	
Ramp-to-ramp demand (veh/h)										

Notes: Adj. = adjustment, Acc. = acceleration, dec. = deceleration.

Exhibit 35-18
Seed File Input Data (Analysis Period No. 1, Segments 11–20)

Segment	11	12	13	14	15	16	17	18	19	20
Type	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
Lanes	3	3	3	3	3	3	3	3	3	3
Free-flow speed (mi/h)	70	70	70	70	70	70	70	70	70	70
Demand (veh/h)	2,800	2,600	2,700	2,700	2,700	2,500	2,600	2,600	2,600	2,600
Capacity adjustment	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
Destination demand adj.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Speed adj.	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
% recreational vehicles	0	0	0	0	0	0	0	0	0	0
On-ramp demand (veh/h)	100		100				100			
On-ramp % trucks	5.0		5.0				5.0			
On-ramp % recreational vehicles	0.0		0.0				0.0			
Off-ramp demand (veh/h)	200				200					
Off-ramp % trucks	5.0				5.0					
Off-ramp % recreational vehicles	0.0				0.0					
Acc./dec. lane length (ft)			300		300		300			
Lanes on ramp	1		1		1		1			
Ramp side	Right		Right		Right		Right			
Ramp free-flow speed (mi/h)	45		45		45		45			
Ramp meter rate (veh/h)	2,100		2,100				2,100			
Ramp-to-ramp demand (veh/h)	32									

Notes: Adj. = adjustment, Acc. = acceleration, dec. = deceleration.

Exhibit 35-19
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.

Exhibit 35-20
Weather Probability, Capacity, Speed, and Demand Data for Example Problem

Weather	Range	Adjustment Factors: Free-Flow Speed	Adjustment Factors: Capacity	Adjustment Factors: Demand	Probability (%)
Clear	N/A	1.00	1.00	1.00	50.0
Light rain	>0.00–0.10 in./h	0.98	0.98	1.00	8.0
Medium rain	>0.10–0.25 in./h	0.94	0.93	1.00	4.0
Heavy rain	>0.25 in./h	0.93	0.86	1.00	2.0
Very light snow	>0.00–0.05 in./h	0.89	0.96	1.00	6.0
Light snow	>0.05–0.10 in./h	0.88	0.91	1.00	3.0
Medium snow	>0.10–0.50 in./h	0.86	0.89	1.00	2.0
Heavy snow	>0.50 in./h	0.85	0.76	1.00	2.0
Moderate wind	>10.00–20.00 mi/h	0.99	0.99	1.00	4.0
High wind	>20.00 mi/h	0.98	0.98	1.00	2.0
Cool	34°F–49.9°F	0.99	0.99	1.00	2.0
Cold	-4°F–33.9°F	0.98	0.98	1.00	2.0
Very cold	<-4°F	0.94	0.91	1.00	3.0
Moderate visibility	0.50–0.99 mi	0.94	0.90	1.00	2.0
Low visibility	0.25–0.49 mi	0.93	0.88	1.00	2.0
Very low visibility	<0.25 mi	0.93	0.88	1.00	6.0
	Average or total	0.97	0.97	1.00	100.0

Note: N/A = not applicable.

Incident Data

Incident data for the past 3 years were obtained from facility incident logs. The log incident types were converted to HCM incident types, and the frequencies were converted into probabilities. The capacity adjustments were obtained from Exhibit 35-5. 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 Exhibit 35-21.

Exhibit 35-21
Incident Probability, Capacity, Speed, and Demand Data for Example Problem

Incident Type	Maximum Lanes Blocked	Free-Flow Speed Adjustment	Capacity Adjustment	Demand Adjustment	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
PDO 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

Notes: N/A = not applicable; PDO = property damage only.

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 Exhibit 35-6. 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 Exhibit 35-22.

Exhibit 35-22
Work Zone Probability, Capacity, Speed, and Demand Data for Example Problem

Work Zone Type	Lanes Open	Capacity (veh/h/ln)	Free-Flow Speed Adjustment	Demand Adjustment	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

Step 2: Generate Scenarios

The seven possible levels of demand, the 16 weather subscenarios, the 13 incident subscenarios, and the seven work zone subscenarios 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 subscenarios and demand levels. From the 10,192 scenarios, 30 are selected for detailed analysis of the effectiveness of the proposed ATDM strategies.

The objective of the ATDM analysis is to estimate the benefits of the various ATDM strategies for a representative cross section of possible demand, weather, incident, and work zone conditions. Therefore, scenarios representing possible combinations of demand weather, incidents, and work zones are targeted and selected.

The limitation of evaluating no more than 30 scenarios was determined at the start of the analysis, on the basis of the resources available for generating and analyzing ATDM strategies. Higher limits on the number of scenarios are possible if resources allow.

The total number of scenarios must be kept to 30 (because of the effort involved in designing custom ATDM strategy responses for each scenario). The following sampling scheme is used for selecting the scenarios:

- Three demand levels (low, medium, high);
- Three weather types (clear, medium rain, light snow);
- Two incident types (no incident, PDO crash blocking one lane); and
- Two work zone types (no work zone, long-term maintaining three lanes open).

The listed subscenarios will result in 36 possible combinations (3 × 3 × 2 × 2), so some will have to be excluded. On the basis of the relative probabilities and the fact that the ATDM strategies to be evaluated do not involve snow strategies, the possible combination of PDO crashes with light snow will not be evaluated.

The 30 scenarios selected for ATDM analysis are given in Exhibit 35-23. Note that the total probability of these scenarios is slightly under 9% (see the "initial probability" column). The HCM analysis results for the 30 scenarios must be weighted to obtain total annual performance over the reliability reporting period for the facility. On the assumption that an unbiased sample has been selected and in light of the 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 rightmost column of Exhibit 35-23.

Exhibit 35-23
Thirty Scenarios Selected for HCM Analysis for Example Problem

Scenario	Demand	Weather	Incident	Work Zones	Initial Probability (%)	Final Probability (%)
1	Low	Clear	None	None	1.7500	19.48
2	Low	Clear	None	Long-term 3	0.1250	1.39
3	Low	Clear	PDO-1	None	0.1400	1.56
4	Low	Clear	PDO-1	Long-term 3	0.0100	0.11
5	Low	Medium rain	None	None	0.1400	1.56
6	Low	Medium rain	None	Long-term 3	0.0100	0.11
7	Low	Medium rain	PDO-1	None	0.0112	0.12
8	Low	Medium rain	PDO-1	Long-term 3	0.0008	0.01
9	Low	Light snow	None	None	0.1050	1.17
10	Low	Light snow	None	Long-term 3	0.0075	0.08
11	Med	Clear	PDO-1	None	0.2800	3.12
12	Med	Clear	PDO-1	Long-term 3	0.0200	0.22
13	Med	Clear	None	None	3.5000	38.96
14	Med	Clear	None	Long-term 3	0.2500	2.78
15	Med	Medium rain	PDO-1	None	0.0224	0.25
16	Med	Medium rain	PDO-1	Long-term 3	0.0016	0.02
17	Med	Medium rain	None	None	0.2800	3.12
18	Med	Medium rain	None	Long-term 3	0.0200	0.22
19	Med	Light snow	PDO-1	None	0.0168	0.19
20	Med	Light snow	PDO-1	Long-term 3	0.0012	0.01
21	High	Clear	None	None	1.7500	19.48
22	High	Clear	None	Long-term 3	0.1250	1.39
23	High	Clear	PDO-1	None	0.1400	1.56
24	High	Clear	PDO-1	Long-term 3	0.0100	0.11
25	High	Medium rain	None	None	0.1400	1.56
26	High	Medium rain	None	Long-term 3	0.0100	0.11
27	High	Medium rain	PDO-1	None	0.0112	0.12
28	High	Medium rain	PDO-1	Long-term 3	0.0008	0.01
29	High	Light snow	None	None	0.1050	1.17
30	High	Light snow	PDO-1	Long-term 3	0.0006	0.01
				Total	8.9841	100.00

Notes: PDO-1 = property damage only crash with one lane blocked; long-term 3 = long-term work zone maintaining three lanes open.

Step 3: Apply Operations Analysis Tool ("Before" ATDM)

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 are also input. The HCM analysis tool is applied 30 times.

When this example problem was developed, the HCM 2010 had not yet incorporated HOV analysis capabilities. Such capabilities are now provided in Chapter 38, Managed Lane Facilities. However, ATDM, travel time reliability, and managed lane analysis were developed by separate research projects and will not be fully incorporated into the HCM's freeway analysis methods until the next HCM update. Therefore, this example problem applies an approximate procedure to evaluate freeway operations with an HOV lane present. In a similar situation, the analyst could apply Chapter 38's methods instead of this approximation.

The HOV lane is assumed to be continuously accessible (thus enabling the standard HCM 2010 freeway analysis procedure to be used with 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. On the basis of Chapter 38, the capacity of a continuous-access HOV lane is assumed to be 1,800 veh/h/ln. This capacity is compared with 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 HCM analysis output is shown in Exhibit 35-24 for each scenario. A summary of the results is provided in Exhibit 35-25. The mean p.m. peak period speed on the facility varies from 16 to 64 mi/h, depending on the scenario. The average annual speed on the facility during the p.m. peak period is 43 mi/h.

Exhibit 35-24
"Before" ATDM Detailed Scenario Results

Scenario Number	Scenario Probability (%)	VMT Demanded	VMT Served	VHD	VHT	Maximum *d/c* Ratio	Max. Travel Time (min)	Mean TTI	Mean Speed (mi/h)	Min. Speed (mi/h)	Max. Queue Length (mi)	% Analysis Periods 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	100,002	100,002	143	1,571	0.96	7.6	1.1	63.6	59.8	0.38	0.0
4	1.1	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	100,002	100,002	262	1,690	0.93	8.4	1.2	59.2	54.4	2.15	0.0
6	17.2	100,002	100,002	389	1,818	1.09	10.6	1.2	55.0	43.3	1.08	25.0
7	8.6	100,002	100,002	270	1,699	1.03	8.4	1.2	58.9	54.4	0.17	0.0
8	0.1	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	100,002	100,002	374	1,803	0.95	8.9	1.3	55.5	51.0	3.41	0.0
10	10.2	100,002	100,002	623	2,051	1.12	12.7	1.4	48.8	36.3	1.79	31.3
11	0.0	107,529	107,529	182	1,718	1.03	7.8	1.1	62.6	58.0	0.19	0.0
12	8.6	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	3.64	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	107,529	107,529	347	1,883	1.11	9.8	1.2	57.1	48.0	0.47	6.3
16	0.4	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	107,529	107,529	312	1,848	1.00	8.7	1.2	58.2	52.1	6.06	0.0
18	17.2	107,529	107,529	849	2,385	1.17	15.1	1.5	45.1	30.0	3.19	43.8
19	0.2	107,529	107,529	504	2,040	1.13	10.9	1.3	52.7	43.8	0.98	18.8
20	5.7	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	6.06	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	111,830	111,830	209	1,807	1.07	8.1	1.1	61.9	56.7	0.28	6.3
24	2.1	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	111,830	111,830	393	1,991	1.04	9.7	1.2	56.2	46.9	1.28	12.5
26	0.2	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	111,830	111,830	451	2,048	1.15	10.9	1.3	54.6	44.0	1.28	25.0
28	0.4	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	111,830	111,830	546	2,143	1.06	10.7	1.3	52.2	42.4	1.76	18.8
30	0.0	111,830	110,887	5,198	6,782	4.02	83.7	4.7	16.3	12.4	6.06	93.8

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; TTI = travel time index; Max. = maximum; Min. = minimum.

Exhibit 35-25
"Before" ATDM Summary Results

Measure of Effectiveness	Value	Units
VMT demanded	25,847,488	veh-mi
VMT served	25,847,198	veh-mi
VHT	603,529	veh-h
VHD	234,285	veh-h
Average speed	42.83	mi/h
Average delay	32.63	s/mi
PTI	3.92	unitless

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index.

Evaluation

The facility is unable to serve all of the VMT demanded, but the shortfall is less than 0.01%.

The PTI (the 95th percentile TTI) 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 Spillover

Scenarios with more than 80% of the 15-min analysis periods at LOS F had a combined probability of occurrence of 9%. Scenarios with maximum queue lengths in excess of 6 mi (the facility length is 7.6 mi) had a probability of occurrence of approximately 7%. This result suggests that queue overflows may occur less than 10% of the time.

Although the congestion overflow occurs mostly for low-probability scenarios, it may result in an underestimation of the delays for the "before" condition. This means that the benefits of ATDM may be underestimated in comparison with the baseline "before" condition. A modest underestimation of the benefits of ATDM may be acceptable, especially if subsequent analysis indicates that the benefits of ATDM support a decision to invest in it. Thus, no correction for congestion spillover (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.

STRATEGY NO. 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 indicates 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 lane that could be used during periods of high congestion or incidents. The maximum HOV demand is 1,350 veh/h, compared with a target capacity of 1,600 veh/h 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 veh/h. To allow for some hysteresis in the tolling–demand cycle, achievement of a target maximum volume of 1,500 veh/h will be assumed.

Step 6: Convert Strategy into Operations Inputs

The HOT lane is assumed to be continuously accessible. 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 veh/h. This capacity is discounted to 1,500 veh/h to allow for inefficiencies in the toll-setting process.

Step 7: Apply Operations Analysis Tool (Opening Day)

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 operation.

Step 8: Compute MOEs (Opening Day)

The scenario-specific results are presented in Exhibit 35-26. The summary MOEs are presented in Exhibit 35-27.

Exhibit 35-26
Scenario-Specific Results: HOT Lane

Scenario Number	Scenario Probability (%)	VMT Demanded	VMT Served	VHD	VHT	Maximum *d/c* Ratio	Max. Travel Time (min)	Mean TTI	Mean Speed (mi/h)	Min. Speed (mi/h)	Max. Queue Length (mi)	% Analysis Periods 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	2.07	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	0.70	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	2.51	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	1.02	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	2.63	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	5.16	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	5.90	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

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; TTI = travel time index; Max. = maximum; Min. = minimum.

Exhibit 35-27
Summary Results: HOT Lane

MOE	MOE Values Before (HOV)	After (HOT)	Difference	Percent Difference	Units
VMT demanded	25,847,488	25,847,488	0	0.0	veh-mi
VMT served	25,847,198	25,847,488	290	0.0	veh-mi
VHT	603,529	561,258	-42,271	-7.5	veh-h
VHD	234,285	192,009	-42,276	-22.0	veh-h
Average speed	42.83	46.05	3.23	7.0	mi/h
Average delay	32.63	26.74	-5.89	-22.0	s/mi
PTI	3.92	3.36	-0.56	-16.5	unitless

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index.

Evaluation

Converting the HOV lane to HOT lane operation results in a 7% reduction in annual VHT, a 22% reduction in annual VHD, and a 7% increase in mean speed on the facility during the p.m. peak period. The average delay per mile is reduced by 22% and the PTI is decreased by 16%. The HOT lane enables the freeway to serve 100% of the VMT demanded.

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

Check for Congestion Spillover

The maximum reported queue is 6.06 mi, which is less than the 7.6-mi facility length. The percentage of 15-min analysis periods with LOS F is 94% or less. The two scenarios with these statistics account for 0.4% of the probability covered by the 30 scenarios, so if there are queue overflows in these two scenarios, they are likely to have little effect on the overall results.

STRATEGY NO. 2: DYNAMIC RAMP METERING

The HOT lane has relieved recurring congestion for the low and medium demand levels, but there is still significant congestion on the facility during incidents and bad weather and on high-demand days (with or without incidents or bad weather). The next strategy to test is the addition of dynamic ramp metering to the ATDM strategy of converting the HOV lane to an 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 Operations 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 with the target maximum desirable flow rate for the freeway. In this example, the target is set at 2,100 veh/h/ln. 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 veh/h/ln.
- The minimum ramp-metering rate is set as 240 veh/h/ln.

- If the number of vehicles stored on the ramp reaches 40 during the analysis, the meter rate is set to the maximum rate until the queue drops below 40.

This analysis is repeated for each ramp for each 15-min 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.

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.

Step 7: Apply Operations Analysis Tool (Opening Day)

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 with dynamic ramp metering.

Step 8: Compute MOEs (Opening Day)

The scenario-specific results are presented in Exhibit 35-28. The summary MOEs are presented in Exhibit 35-29.

Evaluation

Adding locally optimal dynamic ramp metering to HOT lane operation results in an additional 5% reduction in annual VHT, an additional 18% reduction in annual VHD, and an additional 5% increase in mean speed on the facility during the p.m. peak period. The average delay per mile is reduced by 18% compared with the HOT lane alone, and the PTI is decreased by 12% compared with the HOT lane alone.

Check for Congestion Spillover

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

Exhibit 35-28
Detailed Scenario Results: HOT Lane + Dynamic Ramp Metering

Scenario Number	Scenario Probability (%)	VMT Demanded	VMT Served	VHD	VHT	Maximum *d/c* Ratio	Max. Travel Time (min)	Mean TTI	Mean Speed (mi/h)	Min. Speed (mi/h)	Max. Queue Length (mi)	% Analysis Periods 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	2.05	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	0.52	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	2.12	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	0.68	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	2.32	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	4.17	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	4.98	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	1.09	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
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

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; TTI = travel time index; Max. = maximum; Min. = minimum.

Exhibit 35-29
Summary Results: HOT Lane + Dynamic Ramp Metering

MOE	MOE Values: Strategy No. 1 (HOT)	MOE Values: Strategy No. 2 (HOT + Meter)	Difference	Percent Difference	Units
VMT demanded	25,847,488	25,847,488	0	0.0	veh-mi
VMT served	25,847,488	25,847,488	0	0.0	veh-mi
VHT	561,258	531,814	-29,445	-5.5	veh-h
VHD	192,009	162,564	-29,445	-18.1	veh-h
Average speed	46.05	48.60	2.55	5.2	mi/h
Average delay	26.74	22.64	-4.10	-18.1	s/mi
PTI	3.36	2.99	-0.37	-12.4	unitless

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index.

STRATEGY NO. 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 Operations Inputs

Various TDM strategies are considered for reducing recurring demand. A program of strategies that increase in effectiveness 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 p.m. peak period demand levels are expected to be greater than normal. On the basis of an independent assessment, the program is estimated to reduce freeway demands by 1% for low demand levels, by 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 PDO crashes and noncrash incidents. Major employer participation and information dissemination are ramped up when major injury or fatal accidents occur on the facility. Because of the longer durations of fatal and injury crashes, the incident TDM program is expected to be more effective for those types of crashes than for PDO crashes or other noncrash incidents. An independent assessment by the analyst, with other tools, estimates that the incident TDM program will reduce freeway facility demands by 10% for fatal and injury crashes and by 5% for PDO and noncrash incidents.

Step 7: Apply Operations Analysis Tool (Opening Day)

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 (Opening Day)

The scenario-specific results are presented in Exhibit 35-30. The summary MOEs are presented in Exhibit 35-31.

Evaluation

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 VHT, an additional 35% reduction in annual VHD, and an additional 7% increase in mean speed on the facility during the p.m. peak period. The average delay per mile is reduced by 33% compared with the HOT lane and metering, and the PTI is decreased by 18%.

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

Check for Congestion Spillover

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

Exhibit 35-30
Detailed Scenario Results: HOT Lane + Ramp Metering + TDM

Scenario Number	Scenario Probability (%)	VMT Demanded	VMT Served	VHD	VHT	Maximum d/c Ratio	Max. Travel Time (min)	Mean TTI	Mean Speed (mi/h)	Min. Speed (mi/h)	Max. Queue Length (mi)	% Analysis Periods 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	1.79	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	0.44	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	1.87	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	0.60	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	2.00	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	0.40	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	2.90	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	1.19	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	3.65	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	0.57	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	2.06	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	1.98	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	3.63	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

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; TTI = travel time index; Max. = maximum; Min. = minimum.

Exhibit 35-31
Summary Results: HOT Lane + Ramp Metering + TDM

MOE	MOE Values: Strategy No. 2 (HOT + Meter)	MOE Values: Strategy No. 3 (HOT + Meter + TDM)	Difference	Percent Difference	Units
VMT demanded	25,847,488	25,390,134	-457,354	-1.8	veh-mi
VMT served	25,847,488	25,390,134	-457,354	-1.8	veh-mi
VHT	531,814	482,868	-48,945	-10.1	veh-h
VHD	162,564	120,152	-42,412	-35.3	veh-h
Average speed	48.60	52.58	3.98	7.6	mi/h
Average delay	22.64	17.04	-5.61	-32.9	s/mi
PTI	2.99	2.54	-0.45	-17.7	unitless

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index.

Step 8B: Combined Effects of ATDM Investments (Opening Day)

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 Exhibit 35-32.

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

Exhibit 35-32
Summary Results: Combined Effects of the ATDM Plan

MOE	MOE Values Before (HOV)	After (HOT + Meter + TDM)	Difference	Percent Difference	Units
VMT demanded	25,847,488	25,390,134	-457,354	-1.8	veh-mi
VMT served	25,847,198	25,390,134	-457,064	-1.8	veh-mi
VHT	603,529	482,868	-120,661	-20.0	veh-h
VHD	234,285	120,152	-114,133	-48.7	veh-h
Average speed	42.8	52.6	9.75	22.8	mi/h
Average delay	32.6	17.0	-15.59	-47.8	s/mi
PTI	3.92	2.54	-1.38	-35.2	unitless

Notes: VMT = vehicle miles traveled; VHD = vehicle hours of delay; VHT = vehicle hours traveled; PTI = planning time index.

5. USE OF ALTERNATIVE TOOLS

In some cases, finer temporal sensitivity to dynamic changes in the system will be required for the reliability analysis than can be provided by the typical 15-min analysis period used by HCM methods. This may occur in evaluating 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-min durations. There may also be scenarios and configurations that the HCM cannot address, such as complex merging and diverging freeway sections.

The ATDM analysis framework can work with a wide variety of operations analysis tools ranging from microscopic simulation models to mesoscopic simulation models, traffic control optimization models, and 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 guidance documents from FHWA's *Traffic Analysis Toolbox*:

These documents can be downloaded at http://ops.fhwa.dot.gov/trafficanalysistools.

- Volume I: *Traffic Analysis Tools Primer* (*3*);
- Volume II: *Decision Support Methodology for Selecting Traffic Analysis Tools* (*4*); and
- Volume IX: *Work Zone Modeling and Simulation—A Guide for Analysts* (*5*).

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* (*6*);
- Volume IV: *Guidelines for Applying CORSIM Microsimulation Modeling Software* (*7*);
- Volume V: *Traffic Analysis Toolbox Case Studies—Benefits and Applications* (*8*);
- Volume VI: *Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness* (*9*);
- Volume VII: *Predicting Performance with Traffic Analysis Tools* (*10*);
- Volume VIII: *Work Zone Modeling and Simulation—A Guide for Decision-Makers* (*11*);
- Volume X: *Localized Bottleneck Congestion Analysis Focusing on What Analysis Tools Are Available, Necessary and Productive for Localized Congestion Remediation* (*12*);
- Volume XI: *Weather and Traffic Analysis, Modeling and Simulation* (*13*); and
- *Guide on the Consistent Application of Traffic Analysis Tools and Methods* (*14*).

This chapter's conceptual framework for evaluating travel time reliability can be applied to alternative analysis tools in situations where use of the HCM is not appropriate. The same conceptual approach of generating scenarios, assigning scenario probabilities, evaluating scenario performance, and summarizing the results applies when alternative analysis tools, such as microsimulation, are used to estimate reliability effects of operations improvements.

Before embarking on the use of alternative tools, the analyst should consider the much greater analytical demands imposed by a reliability analysis following this chapter's conceptual analysis framework. Thousands of scenarios may need to be analyzed with 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 significant tasks.

If a microscopic simulation analysis tool is used, some adaptations of this chapter's conceptual analysis framework that were fit to the HCM's 15-min analysis periods will no longer be needed:

- Scenarios may be defined differently from and 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-min analysis period.
- Weather start times and durations will no longer need to be rounded to the nearest 15-min analysis period.
- Demand will no longer need to be held constant for the duration of the 15-min analysis period.
- The peak hour factors used to identify the peak 15-min flow rate within the hour would no longer be applied. They would be replaced with the microsimulation model's built-in randomization process.
- This chapter's recommended free-flow speed adjustment factors for weather events and work zones 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 the scenarios are run. Application guidance and typical factors are provided in FHWA's *Traffic Analysis Toolbox*.

If a less disaggregate tool is used (e.g., mesoscopic simulation analysis tool, dynamic traffic assignment tool, demand forecasting tool), many of this chapter's adaptations of the conceptual analysis framework to the HCM may still be appropriate or may need to be aggregated further. 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.

6. REFERENCES

Many of these references are available in the Technical Reference Library in Volume 4.

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12. Dhindsa, A., and N. Spiller. *Traffic Analysis Toolbox Volume X: Localized Bottleneck Congestion Analysis Focusing on What Analysis Tools Are Available, Necessary and Productive for Localized Congestion Remediation*. Report FHWA-HOP-09-042. Federal Highway Administration, Washington, D.C., March 2010.

13. Park, B., T. K. Jones, and S. O. Griffin. *Traffic Analysis Toolbox Volume XI: Weather and Traffic Analysis, Modeling and Simulation*. Report FHWA-JPO-11-019. Federal Highway Administration, Washington, D.C., Dec. 2010.

14. Dowling Associates, Inc. *Guide on the Consistent Application of Traffic Analysis Tools and Methods.* Report FHWA-HRT-11-064. Federal Highway Administration, Washington, D.C., Nov. 2011.

APPENDIX A: INTRODUCTION TO ATDM STRATEGIES

OVERVIEW

More in-depth and up-to-date information on ATDM strategies is available at FHWA's website: http://www.ops.fhwa.dot.gov/atdm.

This section provides brief overviews of typical ATDM strategies for managing demand, capacity, and the performance of the highway and street system. The strategies described here are intended to be illustrative rather than definitive. ATDM strategies constantly evolve as technology advances.

ROADWAY METERING

Roadway metering treatments store surges in demand at various points in the transportation network. Typical examples of roadway metering include freeway on-ramp metering, freeway-to-freeway ramp metering, freeway mainline metering, peak period freeway ramp closures, and arterial signal metering. Exhibit 35-A1 illustrates an example freeway ramp-metering application.

Exhibit 35-A1
Freeway Ramp Metering, SR-94, Lemon Grove, California

Source: FHWA (*A1*).

Roadway metering may be highly dynamic or comparatively static. A comparatively static roadway metering system would establish some preset metering rates on the basis of historical demand data, periodically monitor system performance, and adjust the rates to obtain satisfactory facility performance. A highly dynamic system may monitor system performance on a real-time basis and automatically adjust metering rates by using a predetermined algorithm in response to changes in observed facility conditions. Preferential treatment of high-occupancy vehicles (HOVs) may be part of a roadway metering strategy.

Roadway metering may be applied on freeways or arterials. In the case of arterials, an upstream signal may be used to control the number of vehicles reaching downstream signals. Surges in demand are temporarily stored at the upstream signal and released later when the downstream signals can better serve the vehicles.

CONGESTION PRICING

The objective of congestion pricing is to preserve reliable operating speeds on the tolled facility.

Congestion or value pricing is the practice of charging tolls for the use of all or part of a facility or a central area according to the severity of congestion. The objective of congestion pricing is to preserve reliable operating speeds on the tolled facility with a tolling system that encourages drivers to switch to other times of the day, other modes, or other facilities when demand starts to approach facility capacity. Exhibit 35-A2 shows an example implementation of congestion pricing in Minnesota.

Exhibit 35-A2
Minnesota Dynamic Pricing for HOT Lanes

Source: FHWA (*A2*) (courtesy of Minnesota Department of Transportation).

The tolls may vary by distance traveled, vehicle class, and estimated time savings. Tolls may be collected through electronic or manual means, or both.

Congestion pricing may use different degrees of responsiveness and automation. Some implementations may use a preset schedule, under which the toll varies by the same amount for preset time periods of the day and week. The implementation may be monitored on a regular schedule and the pricing adjusted to achieve or maintain desired facility performance. An advanced implementation of congestion pricing may monitor facility performance much more frequently and use automatic or semiautomatic dynamic pricing to vary the toll on the basis of a predetermined algorithm according to the observed performance of the facility.

High-occupancy toll (HOT) lanes (sometimes also called express lanes) are tolled lanes adjacent to general-purpose lanes. HOT lanes allow motorists to pay tolls to enter the lanes to avoid congested nontoll lanes. HOVs may be allowed to enter the lanes for free or at a reduced toll rate.

Central area pricing is an areawide implementation of congestion pricing.

Central area pricing is an areawide implementation of congestion pricing. It imposes tolls on vehicles entering or traveling within a central area street network during certain hours of certain days. The fee varies by time of day and day of week or according to real-time measurements of congestion within the central area. The toll may be reduced or waived for certain vehicle types, such as HOVs, or for residents of the zone.

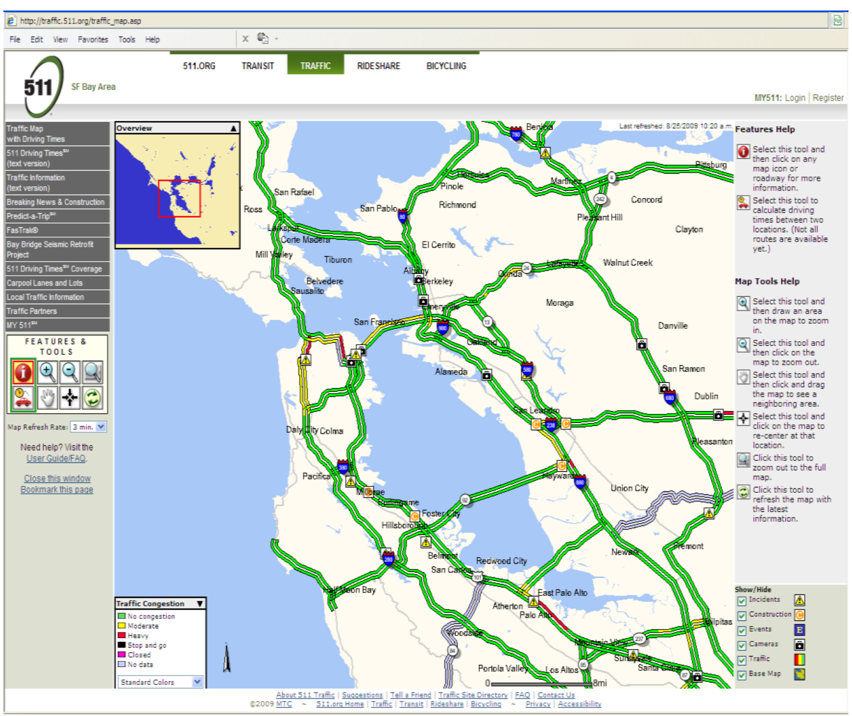
TRAVELER INFORMATION SYSTEMS

Traveler information is an integration of technologies allowing the general public to access real-time or near real-time data on incident conditions, travel time, speed, and possibly other information. Traveler information enhances awareness of current and anticipated traffic conditions on the transportation system.

Traveler information can be grouped into three types (pretrip, in-vehicle, and roadside) according to when the information is made available and how it is delivered to the driver.

Pretrip information is obtained from various sources and is then transmitted to motorists before the start of their trip through various means. Exhibit 35-A3 illustrates Internet transmission of travel information.

Exhibit 35-A3
San Francisco Bay Area
Traffic Map



Source: Copyright 2009 Metropolitan Transportation Commission. http://traffic.511.org.

In-vehicle information may involve route guidance or transmission of incident and travel time conditions to the en route vehicle. Route guidance involves GPS-based real-time data acquisition to calculate the most efficient routes for drivers. This technology allows individual vehicles and their occupants to receive optimal route guidance via various telecommunications devices and provides a method for the transportation network operator to make direct and reliable control decisions to stabilize network flow.

Roadside messages consist of dynamic message signs (also called changeable or variable message signs) and highway advisory radio (also called traveler advisory radio) that display or transmit information on road conditions for travelers while they are on the route.

MANAGED LANES

Managed lanes include reversible lanes, HOV lanes, HOT lanes, truck lanes, speed harmonization, temporary closures for incidents or maintenance, and temporary use of shoulders during peak periods (see Exhibit 35-A4). HOT lanes were described previously under congestion pricing. Speed harmonization is described in a later section.

The term "managed lanes" has been used historically to refer to a broad range of ATDM strategies related to the control of specific lane operations on a facility. That definition is retained here; however, to avoid overlap, only those managed lane strategies not covered elsewhere in this appendix are described in this section.

HOV lanes assign limited vehicle capacity to vehicles that carry the most people on the facility or that in some other way meet societal objectives for reducing the environmental impacts of vehicular travel (e.g., motorcycles, two-seater vehicles, electric vehicles, hybrid vehicles). HOV lanes may operate 24/7 (24 hours a day, 7 days a week) or may be limited to the peak periods when demand is greatest. The minimum vehicle occupancy requirement for the HOV lanes may be adjusted in response to operating conditions in the HOV lanes to preserve uncongested operation.

Exhibit 35-A4
HOV Lane

Source: FHWA (*A3*).

Reversible lanes provide additional capacity for directional peak flows depending on the time of the day. Reversible lanes on freeways may be located in the center of a freeway with gate control on both ends. On interrupted-flow facilities, reversible lanes may be implemented through lane-use control signals and signs that open and close lanes by direction.

The temporary use of shoulders during peak periods by all or a subset of vehicle types can provide additional capacity in a bottleneck section and improve overall facility performance. Temporary shoulder use by transit vehicles in queuing locations can reduce delays for those vehicles by enabling them to reach their exit without having to wait in the mainline queue.

SPEED HARMONIZATION

The objective of speed harmonization is to improve safety and facility operations by reducing the shock waves that typically occur when traffic abruptly slows upstream of a bottleneck or for an incident. The reduction of shock waves reduces the probability of secondary incidents and the loss of capacity associated with incident-related and recurring traffic congestion.

Changeable speed limit or speed advisory signs are typically used to implement speed harmonization. The speed restrictions may apply uniformly across all lanes or may vary by lane. The same lane signs may be used to close individual lanes upstream of an incident until the incident is cleared (this practice is not strictly speed harmonization).

The variable speed limit may be advisory or regulatory. Advisory speeds indicate a recommended speed, which drivers may exceed if they believe doing so is safe under prevailing conditions. Regulatory speed limits may not be exceeded under any conditions. Exhibit 35-A5 shows an example of variable speed limit signs used for speed harmonization in the Netherlands.

Exhibit 35-A5
Variable Speed Limit Signs, Rotterdam, Netherlands

Source: FHWA Active Traffic Management Scan, Jessie Yung.

TRAFFIC SIGNAL CONTROL

Signal timing optimization is the single most cost-effective action that can be taken to improve a roadway corridor's capacity and performance (*A4*). Signal timing is equally as important as the number of lanes in determining the capacity and performance of an urban street.

Traffic signal timing optimization and coordination minimize the stops, delay, and queues for vehicles at individual and multiple signalized intersections.

Traffic signal preemption and priority provide special timing for certain classes of vehicles using the intersection, such as buses, light rail vehicles, emergency response vehicles, and railroad trains. Preemption interrupts the regular signal operation. Priority either extends or advances the time when a priority vehicle obtains the green phase, but generally within the constraints of the regular signal operating scheme.

Traffic-responsive operation and adaptive control provide for different levels of automation in the adjustment of signal timing due to variations in demand. Traffic-responsive operation selects from a prepared set of timing plans on the basis of the observed level of traffic in the system. Adaptive traffic signal control involves advanced detection of traffic, prediction of its arrival at the downstream signal, and adjustment of the downstream signal operation based on that prediction.

SPECIALIZED APPLICATIONS OF ATDM STRATEGIES

ATDM strategies are often applied to the day-to-day operation of a facility. Incident management and work zone management are example applications of one or more ATDM strategies to address specific facility conditions. Employer-based demand management is an example of private-sector applications where traveler information systems may be an important component.

Incident Management

Traffic incident management 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" (*A4*). An incident is "any non-recurring event that causes a reduction in capacity or an abnormal increase in traffic demand that disrupts the normal operation of the transportation system" (*A4*). 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.

Work Zone Management

Work zone management has the objective of 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 are a collection of administrative, procedural, and operational strategies used to manage and mitigate the impacts of a work zone project. The plan 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 or incident management and enforcement strategies. The public information plan describes the public awareness and motorist information strategies (*A4*). ATDM strategies can be important components of a transportation management plan.

Employer-Based Demand Management

Employer-based demand management consists of cooperative actions taken by employers to reduce the impacts of recurring or nonrecurring traffic congestion on employee productivity. For example, a large employer may implement work-at-home or stay-at-home days in response to announced snow days; "spare the air" days; or traffic alerts concerning major construction projects, incidents, and highway facility closures. Another company may contract for or directly provide regular shuttle van service to and from transit stations. Flexible or staggered work hours may be implemented to enable employees to avoid peak commute hours. Ridesharing matching services and incentives may be implemented by the employer to facilitate employee ridesharing.

Employers may use components of a traveler information system to determine appropriate responses to changing traffic conditions. Employees can use traveler information systems in their daily commuting choices.

REFERENCES

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A3. *Managed Lanes: A Primer.* Report FHWA-HOP-05-031. Federal Highway Administration, Washington, D.C., 2005.

A4. *National Signal Timing Optimization Project: Summary Evaluation Report.* Federal Highway Administration and University of Florida, Washington, D.C., May 1982.

APPENDIX B: WEATHER, INCIDENT, AND WORK ZONE FACTORS

OVERVIEW

This appendix provides recommended free-flow speed and capacity adjustment factors for freeway facilities for weather, incidents, and work zones. The information is generally taken from Chapter 10, Freeway Facilities, and research on travel time reliability performed by SHRP 2 Project L08 (*B1*).

WEATHER ADJUSTMENTS

The Chapter 10 capacity reductions and the SHRP 2 Project L08 capacity adjustments generally match for freeways with 65-mi/h free-flow speeds. Consequently, the Chapter 10 capacity reductions (after conversion to the equivalent capacity adjustment factors) were used in combination with the SHRP 2 Project L08 free-flow speed adjustments (selected for 65-mi/h free-flow speed) for the example problem. Where the SHRP 2 Project L08 speed adjustments were lacking, interpolations or extrapolations of the factors were used. The final selected adjustments for the ATDM example problem are shown in Exhibit 35-B1.

Exhibit 35-B1
Capacity and Speed Adjustments for Weather

Weather Type	Range	Speed Adjustment Factor	Capacity Adjustment Factor
Clear	N/A	1.00	1.00
Light rain	>0.00–0.10 in./h	0.98	0.98
Medium rain	>0.10–0.25 in./h	0.94	0.93
Heavy rain	>0.25 in./h	0.93	0.86
Very light snow	>0.00–0.05 in./h	0.89	0.96
Light snow	>0.05–0.10 in./h	0.88	0.91
Medium snow	>0.10–0.50 in./h	0.86	0.89
Heavy snow	>0.50 in./h	0.85	0.76
Low wind	>10.00–20.00 mi/h	0.99	0.99
High wind	>20.00 mi/h	0.98	0.98
Cool	34°F–49.9°F	0.99	0.99
Cold	-4°F–33.9°F	0.98	0.98
Very cold	<-4°F	0.94	0.91
Medium visibility	0.50–0.99 mi	0.94	0.90
Low visibility	0.25–0.49 mi	0.93	0.88
Very low visibility	<0.25 mi	0.93	0.88

Source: Exhibit 10-15 and Vandehey et al. (*B1*).
Note: N/A = not applicable.

INCIDENT ADJUSTMENTS

The recommended free-flow speed and capacity adjustments for incidents are shown in Exhibit 35-B2. The capacity reductions are taken from Chapter 10. Neither Chapter 10 nor SHRP 2 Project L08 provides defaults for free-flow speed adjustments. Preliminary research suggests that incidents may have no effects on free-flow speed; consequently, the recommended adjustment for free-flow speed is 1.00.

Exhibit 35-B2
Default Capacity and Speed Adjustments for Incidents

Incident Type	Maximum Lanes Blocked	Free-Flow Speed Adjustment Factor	Capacity Adjustment Factor
None	None	1.00	1.00
Noncrash incidents	Shoulder	1.00	0.99
	1	1.00	0.79
	2+	1.00	0.61
Property damage only crashes	Shoulder	1.00	0.86
	1	1.00	0.79
	2+	1.00	0.61
Injury crashes	Shoulder	1.00	0.86
	1	1.00	0.79
	2+	1.00	0.61
Fatal crashes	Shoulder	1.00	0.86
	1	1.00	0.79
	2+	1.00	0.61

Source: Derived from Exhibit 10-17.

WORK ZONE ADJUSTMENTS

The capacity reductions are taken from Chapter 10. Neither Chapter 10 nor SHRP 2 Project L08 provides defaults for free-flow speed adjustments; consequently, the free-flow speed reduction is assumed to be equal to the capacity per lane reduction as shown in Exhibit 35-B3.

Exhibit 35-B3
Default Capacity and Speed Adjustments for Work Zones

Type	Lanes Open	Capacity (veh/h/ln)	Speed Adjustment Factor	Capacity Adjustment Factor
None	All	2,000	1.00	1.00
Short-term (1 day or less)	1	1,600	0.80	0.80
	2	1,600	0.80	0.80
	3	1,600	0.80	0.80
Long-term (>1 day)	1	1,400	0.70	0.70
	2	1,450	0.73	0.73
	3	1,500	0.75	0.75

Source: Derived from Exhibit 10-14 and page 10-26.

REFERENCE

B1. Vandehey, M., W. Kittelson, P. Ryus, R. Dowling, J. Zegeer, N. Rouphail, B. Schroeder, A. Hajbabaie, B. Aghdashi, T. Chase, S. Sajjadi, R. Margiotta, J. Bonneson, and L. Elefteriadou. *Incorporation of Travel Time Reliability into the HCM.* SHRP 2 Project L08 Final Report. Kittelson & Associates, Inc., Portland, Ore., Aug. 2013.

APPENDIX C: INCIDENT DURATIONS AND FREQUENCIES

OVERVIEW

This appendix provides a procedure for estimating freeway incidents from crash data and provides recommended default durations for incidents on freeway facilities.

PREDICTING INCIDENTS FROM CRASH DATA

This approach is appropriate for facilities where incident logs are not routinely prepared, are inadequately detailed, or 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).

The approach expands the reported crashes to total incidents by using an expansion factor obtained from research (*C1*). The probabilities of incidents by severity and lane blockage type are computed with Equation 35-C1.

$$P(inc, sev, block) = P(inc) \times P(sev) \times P(block)$$

Equation 35-C1

where

$P(inc, sev, block)$ = probability of incident with severity type *sev* and lane blockage type *block*;

$P(inc)$ = probability of incident occurring on facility within the daily study period;

$P(sev)$ = probability of incident being one of the following severity types: fatal, injury, property damage only (PDO), noncrash; and

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

The probability of an incident occurring, $P(inc)$, is equal to 1 minus the probability of no incidents occurring within the study period. On the assumption of a Poisson distribution of incidents for the study period, the probability of no incidents = $\exp(-\lambda)$, where λ is the average number of incidents per study period.

When the Poisson probability of zero incidents within the study period is substituted, the following is obtained:

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

Equation 35-C2

where all variables are as defined previously.

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

1. Estimate the annual crashes occurring within the reliability reporting period for the year.
    a. Assume that crashes are proportional to the volume on the facility.
    b. Multiply total crashes per year by the percent of average annual daily traffic (AADT) occurring during the study period.

   c. For example, if the peak hour is typically 10% of AADT 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.
   a. Divide the annual crashes in the reliability reporting period by the number of days in the reliability reporting period.
   b. For example, if the reliability reporting period is the p.m. 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).
   c. If the facility has 520 crashes per year, with 10% occurring during the weekday p.m. peak hour, then there are on average 520 × 10% / 260 = 0.20 crash per daily study period.
3. Expand crashes per daily study period to total incidents (crashes plus noncrash incidents) per daily study period.
   a. Use an expansion factor for freeways of 4.9 (*C1*) to expand crashes to incidents.
   b. To continue the previous example, 0.20 crash per daily study period × 4.9 = 0.98 incident per daily study period.
4. Compute the probability of *no* incidents occurring during a daily study period.
   a. Assume that incidents occur independently of the time since the last event, giving their probability of occurrence within the study period a Poisson distribution with a mean equal to the average number of incidents per daily study period.
   b. Compute the probability of zero incidents within the study period by using a Poisson distribution with a mean equal to the average number of incidents per daily study period.
   c. To continue 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.
   a. The proportions of noncrash incidents and PDO, injury, and fatal crashes can be obtained from Exhibit 35-C1.
   b. If facility-specific data on crash proportions are available, those proportions should be used instead. The facility-specific proportions will need to be adjusted to account for noncrash incidents to ensure that the crash and noncrash proportions add up to 1.
6. Allocate crashes and noncrashes by lane closures by using the proportions for freeways estimated from incident data tabulated for various U.S. freeways in Exhibit 35-C2.

Exhibit 35-C1
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%

Notes: The ratio of total incidents to crashes is 4.9 (*C1*). The crashes are proportioned among PDO, injury, and fatal crashes on the basis of national statistics reported in Chapter 2, Table 24, of *Traffic Safety Facts* (*C2*).

Exhibit 35-C2
Default Proportions for Incident Lane Blockage

Incident Type	Blocking Shoulder	Blocking One Lane	Blocking Two 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: Vandehey et al. (*C1*).

INCIDENT DURATION

The incident duration information is taken from supporting information developed by SHRP 2 Project L08 (*C1*). The recommended default values are shown in Exhibit 35-C3.

Exhibit 35-C3
Default Durations for Incident Lane Blockage

Incident Type	Maximum Lanes Blocked	Duration (min)
No incident	N/A	N/A
Noncrash	Shoulder	30
	1	30
	2+	60
PDO crash	Shoulder	45
	1	45
	2+	60
Injury crash	Shoulder	60
	1	60
	2+	60
Fatal crash	Shoulder	150
	1	150
	2+	150

Note: N/A = not applicable.

REFERENCES

C1. Vandehey, M., W. Kittelson, P. Ryus, R. Dowling, J. Zegeer, N. Rouphail, B. Schroeder, A. Hajbabaie, B. Aghdashi, T. Chase, S. Sajjadi, R. Margiotta, J. Bonneson, and L. Elefteriadou. *Incorporation of Travel Time Reliability into the HCM.* SHRP 2 Project L08 Final Report. Kittelson & Associates, Inc., Portland, Ore., Aug. 2013.

C2. *Traffic Safety Facts 2010.* Report DOT HS 811 659. National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., 2012.

APPENDIX D: EFFECTS OF INCIDENT DURATION REDUCTIONS

OVERVIEW

This appendix describes the procedure for estimating the free-flow speed and capacity effects of ATDM measures to reduce incident duration on freeway facilities.

METHOD

Reductions in incident duration due to traffic incident management (TIM) strategies are estimated by the analyst for each incident type. Incident duration is the sum of the incident detection, verification, response, and clearance. 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 used in the 2010 HCM freeway analysis method is 15 min, the effects of small reductions in incident duration are approximated by increasing the 15-min capacity of the freeway on the basis of the formulas in this appendix.

As shown in Exhibit 35-D1, the capacity gained by shortening the incident duration is the following:

Equation 35-D1

$$CapGained = (c_1 - c_2) \times (1 - x)t$$

where

$CapGained$ = capacity gained (veh),

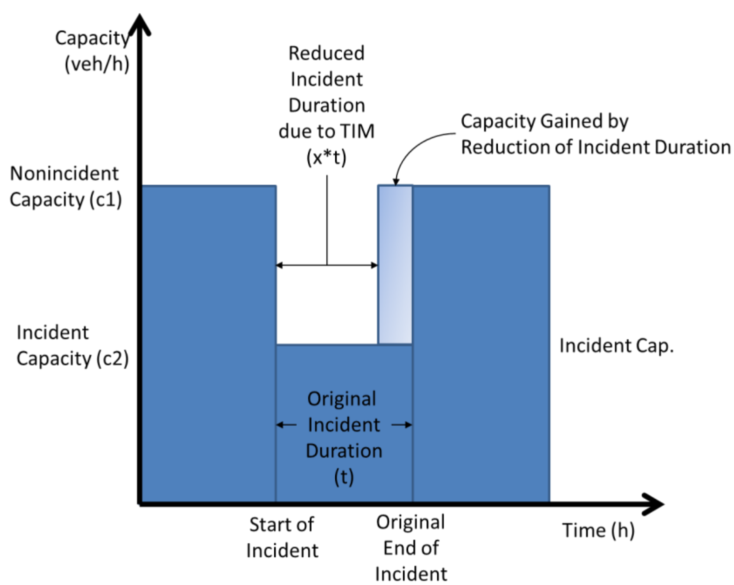
c_1 = capacity before and after the incident (veh/h),

c_2 = capacity during the incident (veh/h),

t = incident duration (h), and

x = proportional reduction in incident duration (unitless).

Exhibit 35-D1
Capacity Gained by Reducing Incident Duration



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

$$AveCap = \frac{(c_2 \times x \times t) + (c_1 \times [1 - x]t)}{t}$$

Equation 35-D2

where $AveCap$ is the average capacity over the original incident duration (veh/h) and all other variables are the same as before.

The original capacity adjustment factor for the incident ($y = c_2 / c_1$) becomes $AveCap / c_1$:

$$AveCapFac = \frac{c_2}{c_1}x + (1 - x) = (y - 1)x + 1$$

Equation 35-D3

where

$AveCapFac$ = new average capacity adjustment factor reflecting shortened incident duration (unitless),

y = original capacity adjustment factor for incident (unitless), and

x = proportional reduction in incident duration (unitless).

All other variables are as previously defined.

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

$$AveSpdFac = \frac{s_2}{s_1}x + (1 - x) = (z - 1)x + 1$$

Equation 35-D4

where

$AveSpdFac$ = new average speed adjustment factor reflecting shortened incident duration (unitless),

s_1 = free-flow speed before and after the incident (mi/h),

s_2 = free-flow speed during the incident (mi/h),

z = original free-flow speed adjustment factor for incident (unitless), and

x = proportional reduction in incident duration (unitless).

Demand is not adjusted for the shorter incident duration.

APPENDIX E: EFFECTS OF HOV–HOT LANE STRATEGIES

This appendix was developed at the same time Chapter 38 (Managed Lane Facilities) was being developed by a separate research project.

References to the inability of the HCM to evaluate managed lanes allude to the original HCM 2010. The analyst may wish to consider applying Chapter 38's methods as an alternative to this appendix's approach.

It is anticipated that the ATDM and managed lanes methods will be integrated into the HCM's freeway facilities method in the next major HCM update.

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 original HCM 2010 freeway method.

The operation and performance of barrier-separated (painted or physical), limited-access HOV lanes cannot be evaluated with the original 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.

Any HOV lanes are assumed to be located in the leftmost lanes. From Exhibit 38-12 in Chapter 38, Managed Lane Facilities, the capacity of a continuous-access HOV lane ranges from 1,600 to 1,800 veh/h, depending on the lane's free-flow speed.

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. When there are not enough eligible HOVs plus violators to fill an HOV lane, the capacity of the HOV lane is set at the lower value, the number of eligible HOVs plus violators.

Equation 35-E1

$$AveCap(s) = \frac{CapHOV(s) \times HOVlanes(s) + CapMFlanes(s) \times MFlanes(s)}{HOVlanes(s) + MFlanes(s)}$$

where

$AveCap(s)$ = average capacity per lane for section s (veh/h/ln),

$CapHOV(s)$ = min (capacity per HOV lane, eligible HOVs per HOV lane) for section s (veh/h/ln),

$HOVlanes(s)$ = number of HOV lanes in section s (ln),

$CapMFlanes(s)$ = capacity per mixed-flow lane in section s (veh/h/ln), and

$MFlanes(s)$ = number of mixed-flow lanes in section s (ln).

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 VEHICLES

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

Since the original 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 revert to those of the adjacent mixed-flow lanes.

CONVERT MIXED-FLOW LANES TO HOT LANES

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

The toll is assumed to be set as necessary to guarantee that any HOT lanes are fully utilized. Thus, regardless of the number of eligible HOVs that can use the HOT lane for free (or a reduced rate), the HOT lane is always assumed to carry its 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.

Equation 35-E2

$$AveCap(s) = \frac{CapHOT(s) \times HOTlanes(s) + CapMFlanes(s) \times MFlanes(s)}{HOTlanes(s) + MFlanes(s)}$$

where

$AveCap(s)$ = average capacity per lane for section s (veh/h/ln),

$CapHOT(s)$ = capacity per HOT lane for section s (veh/h/ln),

$HOTlanes(s)$ = number of HOT lanes in section s (ln),

$CapMFlanes(s)$ = capacity per mixed-flow lane in section s (veh/h/ln), and

$MFlanes(s)$ = number of mixed-flow lanes in section s (ln).

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 HOT lanes.

HOT LANES OPENED TO ALL VEHICLES

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 F: EFFECTS OF SHOULDER AND MEDIAN LANE STRATEGIES

This appendix provides details on the free-flow speed and capacity adjustments associated with 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 Chapter 10 freeway facilities method to be the same as that of a regular lane; however, utilization of the auxiliary lane may be lower than that of a through lane. In addition, the freeway method does not provide a capacity for shoulder lanes. Until 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 (i.e., 1,050 veh/h).

Since the freeway facilities method does not recognize individual lane capacities, computation of an average capacity for freeway sections with auxiliary shoulder lanes across all lanes is necessary.

Equation 35-F1

$$AveCap(s) = \frac{CapShldr(s) + CapMFlanes(s) \times MFlanes(s)}{1 + MFlanes(s)}$$

where

AveCap(*s*) = average capacity per lane for section *s* (veh/h/ln),

CapShldr(*s*) = capacity per shoulder lane for section *s* (veh/h/ln),

CapMFlanes(*s*) = capacity per mixed-flow lane in section *s* (veh/h/ln), and

MFlanes(*s*) = number of mixed-flow lanes in section *s* (ln).

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

Until 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 are used to compute freeway section capacities, lanes, and free-flow speeds where buses are allowed on shoulders, with the following exception: the capacity of the shoulder lane is the number of buses per hour using the shoulder lane or the user-specified capacity, whichever is less (the 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 are used to compute freeway section capacities, lanes, and free-flow speeds where HOVs are allowed on shoulders, with the following exception: the 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 are used to compute freeway section capacities, lanes, and free-flow speeds where all vehicles are allowed on shoulders, with the following exception: the 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 are used to compute freeway section capacities, lanes, and free-flow speeds, with the following exception: the 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 are used to compute freeway section capacities, lanes, and free-flow speeds, with the following exception: the 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 are used to compute freeway section capacities, lanes, and free-flow speeds, with the following exception: the capacity of the median lane is as designated by the user.

APPENDIX G: EFFECTS OF RAMP-METERING STRATEGIES

This appendix provides details on the free-flow speed and capacity adjustments associated with ramp-metering strategies.

The Chapter 10 freeway facilities 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 ramp metering is in operation (*G1*).

LOCALLY DYNAMIC RAMP METERING

For locally dynamic ramp metering, an adaptation of the ALINEA algorithm (*G2*) is used to estimate the ramp-metering rate for each analysis period for each scenario:

Equation 35-G1

$$R(t) = \frac{(CM - VM(t))}{NR}$$

subject to

$$MinRate < R(t) < MaxRate$$

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

where

$R(t)$ = ramp-metering rate for analysis period t (veh/h/ln),

NR = numbered of metered lanes on ramp (ln),

CM = capacity of downstream section (veh/h),

$VM(t)$ = volume on upstream section for analysis period t (veh/h),

$VR(t)$ = volume on ramp during analysis period t (veh/h),

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

QRS = queue storage capacity of ramp (veh),

$MinRate$ = user-defined minimum ramp-metering rate (veh/h/ln) (default value is 240 veh/h/ln), and

$MaxRate$ = user-defined maximum ramp-metering rate (veh/h/ln) (default value is 900 veh/h/ln).

REFERENCES

G1. Jacobson, L., J. Stribiak, L. Nelson, and D. Sallman. *Ramp Management and Control Handbook.* Report FHWA-HOP-06-001. Federal Highway Administration, Washington, D.C., Jan. 2006.

G2. Papageorgiou, M., H. Hadj-Salem, and J.-M. Blosseville. ALINEA: A Local Feedback Control Law for On-Ramp Metering. In *Transportation Research Record 1320,* Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 58–64.

APPENDIX H: 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 (TDM) element will address how demand management will be used to address recurring congestion on the facility.
- The weather traffic management plan (W-TMP) element will identify the ATDM strategies to be used 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 used for incidents. The TIM will have a TDM component for managing demand on the facility during incidents.
- The work zone traffic management plan (WZ-TMP) element will identify the ATDM strategies to be used for work zones. The WZ-TMP will have a TDM component for managing 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

FHWA's Travel Demand Management Toolbox website provides resources to help manage traffic congestion by better managing demand. These resources include publications, web links, and training offerings. Demand management strategies include the following (*H1*):

http://ops.fhwa.dot.gov/tdm/toolbox.htm

- 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 workweek programs
- Location- and design-targeted strategies
  - Transit-oriented development
  - Live near your work
  - Proximate commute

FHWA's guide on this topic (*H1*) should be consulted for more information on designing the TDM element of an ATDM program.

WEATHER-RESPONSIVE TRAFFIC MANAGEMENT PLANS

Weather-responsive traffic management 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 forecast weather conditions (*H2*).

Weather-responsive traffic management strategies include the following:

- Motorist advisory, alert, and warning systems,
- Speed management strategies,
- Vehicle restrictions strategies,
- Road restriction strategies,
- Traffic signal control strategies,
- Traffic incident management,
- Personnel and asset management, and

- Agency coordination and integration.

FHWA's report on this topic (*H2*) should be consulted for additional information on the design and selection of weather-responsive traffic management strategies.

TRAFFIC INCIDENT MANAGEMENT PLANS

An FHWA handbook (*H3*) provides information on the design of TIM plans.

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 non-recurring event that causes a reduction in capacity or an abnormal increase in traffic demand that disrupts the normal operation of the transportation system" (*H4*). 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 and 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 pre-positioned and interagency communications established to respond rapidly and effectively to an incident. The TIM plan may include measures in effect 24 hours a day and 7 days a week, weekdays only, weekday peak periods, or any other periods 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 (e.g., spilling coffee), on the side of the road, or in the opposite 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.

Section 6I.01 of the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD, *H5*) classifies incidents according to their expected duration:

- "Extended" duration incidents are those expected to persist for more than 24 h and should be treated like work zones.
- "Major" incidents have expected durations of more than 2 h.
- "Intermediate" incidents have expected durations of 0.5 h up to and including 2 h.
- "Minor" incidents are expected to persist for less than 30 min.

Stages of Incident Management

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

- Detection;
- Verification;
- Response;
- Motorist information; and
- Site management, consisting of
  - 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 transportation management center, or maintenance or 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 to enable them to 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 the following three major tasks:

- *Traffic management*, which is the control of and safe movement of traffic through the incident zone;
- *Investigation*, which documents the causes of traffic incidents for legal and insurance purposes; and
- *Clearance*, which 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 (*H3*):

1. Management objectives and performance measurement;
2. Designated interagency teams' membership, roles, and responsibilities;
3. Response and clearance policies and procedures; and
4. Responder and motorist safety laws and equipment.

Incident Response and Clearance Strategies

The incident management plan will designate the responder roles and responsibilities, establish an incident command system with a unified command across agencies, identify who is responsible for bringing which equipment and resources to the incident site, establish response and clearance procedures by responding agency and by incident type, and identify state and local laws that apply to incident clearance procedures.

Exhibit 35-H1 presents a menu of possible incident management strategy improvements that an agency may wish to evaluate by using the ATDM analysis procedure (*H6*). The expected effect of each class of strategies on highway capacities and speeds is included in this exhibit.

Exhibit 35-H1
Possible Incident Management Strategies

Strategy	Description
Improved detection and verification	Closed-circuit TV, routine service patrol, or other continuously monitored incident detection system to spot incidents more quickly and verify the required resources to clear the incident. Enhanced 911, automated positioning systems, motorist aid call boxes, and automated collision notification systems are included.
Traveler information system	511 systems, traveler information websites, media partnerships, dynamic message signs, standardized dynamic message sign message sets, and usage protocols to improve the information available to travelers.
Response	Personnel and equipment resource lists, towing and recovery vehicle identification guide, instant tow dispatch procedures, towing and recovery zone based contracts, enhanced computer-aided dispatch, dual or optimized dispatch procedures, motorcycle patrols, equipment staging areas or pre-positioned equipment.
Scene management and traffic control	Incident command system, response vehicle parking plans, high-visibility safety apparel and vehicle markings, on-scene emergency lighting procedures, safe and 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.
Quick clearance and recovery	Abandoned-vehicle laws, safe and quick clearance laws, service patrols, vehicle-mounted push bumpers, incident investigation sites, noncargo vehicle fluid discharge policy, fatality certification and removal policy, expedited crash investigation, quick clearance using fire apparatus, towing and recovery quick clearance incentives, major incident response teams.

Source: Adapted from Carson (*H6*).

WORK ZONE TRANSPORTATION MANAGEMENT PLANS

Work zone management has the objective of 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 and incident management and enforcement strategies. The public information plan describes the public awareness and motorist information strategies (*H4*). ATDM strategies can be important components of a TMP (*H7*).

The WZ-MOTP codifies the agency's management strategy. It has the following elements:

- *Construction approach*—staging, sequencing, lane and ramp closure alternatives, alternative work schedules (e.g., 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, and physical barriers.
- *Public information*—a mix of dynamic (ATDM) and static pretrip and en route information (e.g., 511, newspapers, meetings, websites, closed-circuit television over the Internet), plus on-site information signing such as static signs, changeable or variable message signs, and highway advisory radio (HAR).
- *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 systems (ITS), emergency service patrols, hazardous materials 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 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 the following:

1. Complete closure of the work area for a short time versus partial closure for a 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 MOTP 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 MUTCD defines work zone types according to the duration and time of day (*H5*):

- *Duration Type A*: long-term stationary work that occupies a location more than 3 days;
- *Duration Type B*: intermediate-term stationary work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 h;
- *Duration Type C*: short-term stationary daytime work that occupies a location for more than 1 h within a single daylight period;
- *Duration Type D*: short-duration work that occupies a location up to 1 h; and
- *Duration Type E*: mobile work that moves intermittently or continuously.

Work zones are further categorized by the MUTCD in 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 (*H5*).

- *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-ft lane (Section G6.08);
- *Location Type D*: within the median (Section G6.09); and
- *Location Type E*: within the traveled way of
  - A two-lane highway (Section 6G.10),
  - An urban street (Section 6G.11),
  - A multilane non–access-controlled highway (Section 6G.12),
  - An intersection (Section 6G.13), or
  - A freeway or an expressway (Section 6G.14).

Each work zone type has an associated typical application of temporary traffic controls. They are described in MUTCD Section 6H-1 (*H5*).

Public Information Element

The public information element is intended to provide the public with pretrip and en route information and with 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 websites; and on-site web-accessible closed-circuit cameras, variable message signs, and HAR.

Travel Demand Management Element

The TDM element identifies incentives that will be provided for alternative modes, such as park-and-ride lots, in coordination with the public information element. The public information element and the TDM element are different in that the public information is neutral, 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. The plans describe the coordination with traffic management centers, the use of ITS devices, deployment of emergency service patrols in the work zone, and enhanced police enforcement. Enforcement may be strengthened 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 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 time. Traffic control officers, temporary cones and signs, reversible lanes, and special signal control plans are often part of a special event management plan (*H8*).

A special event management plan typically has the following components:

- Before-event ingress control,
- During-event access control, and
- Postevent 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 and out of the event venue, much like a short-term work zone.

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