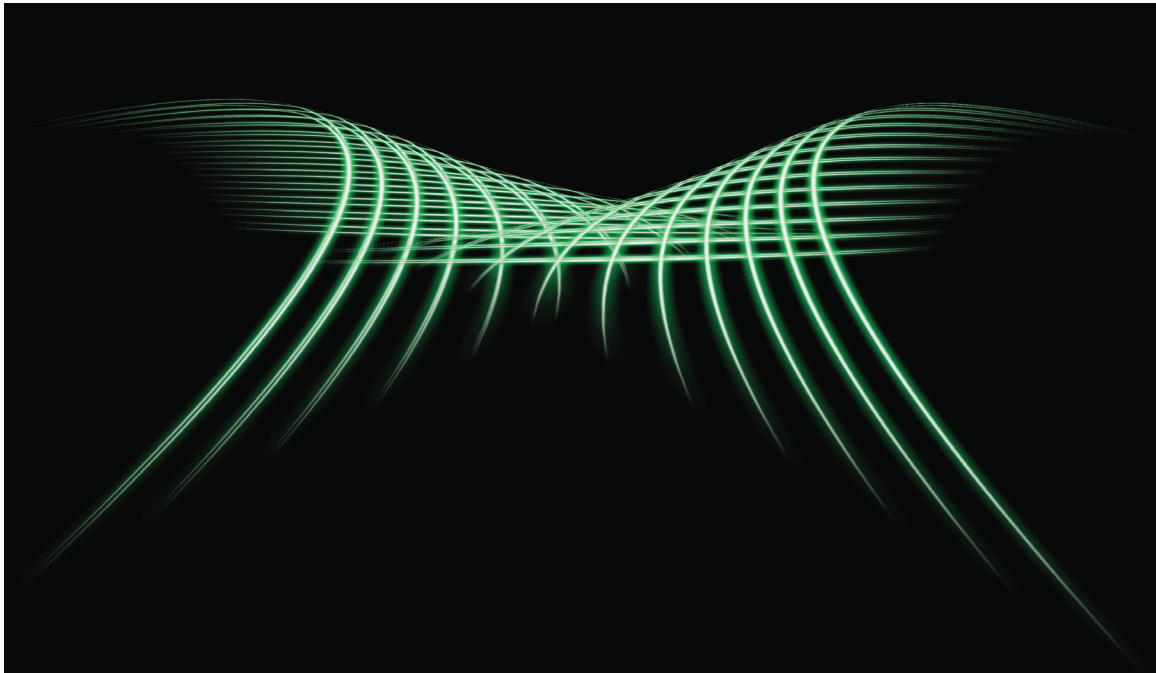


HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 35

ACTIVE TRAFFIC MANAGEMENT



TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

WASHINGTON, DC | WWW.TRB.ORG

HCM2010

HIGHWAY CAPACITY MANUAL

The HCM 2010 significantly enhances how engineers and planners assess the traffic and environmental effects of highway projects by

- Providing an integrated multimodal approach to the analysis and evaluation of urban streets from the points of view of automobile drivers, transit passengers, bicyclists, and pedestrians;
- Addressing the proper application of microsimulation analysis and the evaluation of the results;
- Examining active traffic management in relation to demand and capacity; and
- Exploring specific tools and generalized service volume tables to assist planners in quickly sizing future facilities.



The HCM 2010 consists of four volumes:

Volume 1: Concepts;
Volume 2: Uninterrupted Flow;
Volume 3: Interrupted Flow; and
Volume 4: Applications Guide (electronic only).

The four-volume format provides information at several levels of detail, to help users more easily apply and understand the concepts, methodologies, and potential applications.

Volumes 1, 2, and 3 are issued as a boxed set. Volume 4 is electronic only, accessible to registered HCM users via the Internet, and includes four types of content: supplemental chapters on methodological details and emerging issues; interpretations, clarifications, and corrections; comprehensive case studies; and a technical reference library.

To order HCM 2010, go to <http://books.trbbookstore.org/hcm10.aspx>.

For more information about HCM 2010 and TRB publications, contact the Transportation Research Board Business Office, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-3213; fax 202-334-2519; e-mail TRBsales@nas.edu; or through the Internet, www.trb.org).

CHAPTER 35

ACTIVE TRAFFIC MANAGEMENT

CONTENTS

1. INTRODUCTION.....	35-1
Purpose	35-1
Organization.....	35-2
Scope and Limitations.....	35-2
2. ACTIVE TRAFFIC MANAGEMENT STRATEGIES	35-3
Overview	35-3
Roadway Metering	35-3
Congestion Pricing	35-4
Traveler Information Systems.....	35-5
Managed Lanes	35-6
Speed Harmonization	35-7
Traffic Signal Control	35-7
Specialized Applications of ATM Strategies.....	35-8
3. METAMEASURES OF EFFECTIVENESS.....	35-10
Introduction.....	35-10
Need for Meta-MOE's	35-10
Candidate Meta-MOE's	35-10
Indices of Performance	35-11
4. GENERAL EFFECTS	35-12
Introduction.....	35-12
Roadway Metering	35-12
Congestion Pricing	35-13
Traveler Information Systems.....	35-14
Managed Lanes	35-15
Traffic Signal Control	35-17
Speed Harmonization	35-18
5. REFERENCES	35-19

LIST OF EXHIBITS

Exhibit 35-1 Freeway Ramp Metering, SR-94, Lemon Grove, California.....	35-3
Exhibit 35-2 Minnesota Dynamic Pricing for HOT Lanes	35-4
Exhibit 35-3 San Francisco Bay Area Traffic Map	35-5
Exhibit 35-4 HOV Lane	35-6
Exhibit 35-5 Variable Speed Limit Signs, Rotterdam, Netherlands	35-7

1. INTRODUCTION

Active traffic management (ATM) is a comprehensive approach to optimizing the operational performance of the roadway system through monitoring and control of systems operations. ATM incorporates both demand and supply management strategies. Management of both demand and supply greatly enhances the ability of the transportation agency to achieve its system performance goals.

ATM can range from the simple to the complex. It may be relatively static, with routine monitoring of system performance and periodic changes to system controls in response to those measurements, or it may be highly dynamic, using sophisticated technology to update system controls continuously and automatically in response to real-time information on system conditions.

This chapter focuses on the following major ATM strategies:

- Roadway metering,
- Congestion pricing,
- Traveler information systems,
- Managed lanes,
- Traffic signal control, and
- Speed harmonization.

ATM strategies, however, are evolving as quickly as the technologies they employ. The above list is illustrative, not definitive, of ATM. New ATM strategies and variations are created with every advance in detection, communications, and control technology.

ATM strategies may be significant components of incident management plans, work zone management plans, and employer-based demand management programs.

PURPOSE

This chapter is ultimately intended to provide recommended methodologies and measures of effectiveness (MOEs) for evaluating the impacts of ATM strategies on highway and street system demand, capacity, and performance. However, at this time available information on the performance of ATM strategies has not matured sufficiently to enable the development and presentation of specific analysis methodologies. Consequently, this chapter limits itself to describing ATM strategies; discussing the mechanisms by which they affect demand, capacity, and performance; and offering general guidance on possible evaluation methods for ATM techniques. Later generations of this chapter will provide more specific guidance on the evaluation of ATM strategies.

This first-generation chapter is intended to lead to more specific guidance in future HCM updates.

ORGANIZATION

This chapter is organized as follows:

Introduction—Describes the chapter's scope, purpose, limitations, and organization.

ATM Strategies—Provides an overview of ATM strategies.

Meta-Measures of Effectiveness—Presents recommended meta-measures of effectiveness (meta-MOE) that build on traditional *Highway Capacity Manual* (HCM) measures for assessing the effectiveness of ATM strategies.

Effectiveness—Serves as a stand-in for future sections on methodology and applications. It gives a general description of the mechanisms by which ATM strategies can affect demand, capacity, and performance; summarizes available evidence on the effects; and suggests possible analysis tools.

SCOPE AND LIMITATIONS

This chapter presents introductory information on ATM strategies and their effect on demand, capacity, and system performance.

Because research on ATM is still in its infancy, no specific methodologies are presented for evaluating the effects of ATM strategies. As of this writing a good deal of research on ATM strategies, methodologies, and MOEs is under way at the federal and state levels; the analyst is advised to consult the original research to better understand the basis and limitations of the tentative results cited in this chapter.

2. ACTIVE TRAFFIC MANAGEMENT STRATEGIES

OVERVIEW

This section provides brief overviews of typical ATM strategies for managing demand, capacity, and performance for the highway and street system. The strategies described here are intended to be illustrative rather than definitive. ATM strategies are constantly evolving with each advance in technology.

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 35-1 illustrates a freeway ramp-metering application.



Source: Federal Highway Administration, *Ramp Management and Control: A Primer (1)*.

Exhibit 35-1
Freeway Ramp Metering, SR-94,
Lemon Grove, California

Roadway metering may be highly dynamic or comparatively static. A comparatively static roadway metering system would establish 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 and automatically adjust metering rates on a real-time basis 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. An upstream signal may be used on arterials to control the number of vehicles reaching downstream signals. Surges in demand are temporarily stored at the upstream signal and released when the downstream signals can better serve the vehicles.

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

Exhibit 35-2
Minnesota Dynamic Pricing
for HOT Lanes

CONGESTION PRICING

Congestion or value pricing is the practice of charging tolls for 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 35-2 shows an example of congestion pricing in Minnesota.



Source: Federal Highway Administration, *Technologies That Complement Congestion Pricing (2)* (courtesy of Minnesota Department of Transportation).

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

Congestion pricing may employ different degrees of responsiveness and automation. Some implementations may use a preset schedule in which the toll varies by the same amount for preset times during 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 more frequently and use automatic or semiautomatic dynamic pricing, varying the toll by using a predetermined algorithm according to the observed performance of the facility.

High-occupancy toll (HOT) lanes (sometimes called express lanes) are tolled lanes adjacent to general-purpose lanes. Motorists pay tolls to enter the HOT

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 that imposes tolls for vehicles both entering and traveling within a central area street network during certain hours of certain days. The fee varies by time of day, by 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 that allow the general public to access real-time or near real-time data on traffic factors such as incident conditions, travel time, and speed. Traveler information systems can be divided 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 transmitted to motorists before the start of their trip through various means. Exhibit 35-3 illustrates internet transmission of travel information.

Central area pricing is an areawide implementation of congestion pricing.

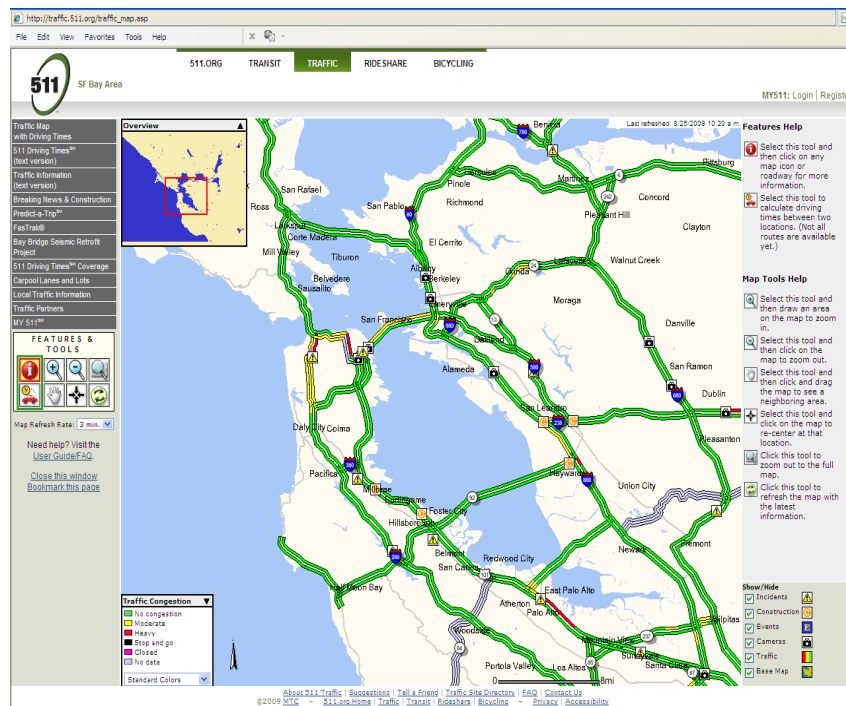


Exhibit 35-3
San Francisco Bay Area Traffic Map

Source: Metropolitan Transportation Commission, copyright 2009. <http://traffic.511.org>.

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

The term "managed lanes" has historically referred to a broad range of ATM strategies related to the control of specific lane operations on a facility. That definition is retained here, but to avoid overlap, only those managed lane strategies not covered elsewhere in this chapter are described in the Managed Lanes section.

Exhibit 35-4
HOV Lane

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 en route.

MANAGED LANES

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 (see Exhibit 35-4). HOT lanes are described above under congestion pricing; speed harmonization is described in a later 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 or two-seater, electric, or hybrid vehicles). HOV lanes may operate 24 hours a day, 7 days a week, or may be limited to peak periods when demand is greatest. The minimum vehicle occupancy requirement for HOV lanes may be adjusted in response to operating conditions in the HOV lanes to preserve uncongested operation.



Source: Federal Highway Administration, *Managed Lanes: A Primer* (3).

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 with the help of 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 decreases 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. Although not strictly a speed harmonization technique, the same lane signs may be used to close individual lanes upstream of an incident until the incident is cleared.

The variable speed limit may be advisory or regulatory. Advisory speeds indicate a recommended speed that drivers may exceed if they believe it is safe under prevailing conditions. Regulatory speed limits may not be exceeded under any conditions. Exhibit 35-5 shows an example of variable speed limit signs used for speed harmonization in the Netherlands.



Source: Federal Highway Administration, ATM Scan, Jessie Yung.

Exhibit 35-5
Variable Speed Limit Signs,
Rotterdam, Netherlands

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 (4). Signal timing is equal in importance to the number of lanes in determining the capacity and performance of an urban street.

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

Traffic signal preemption or priority provides special timing for certain classes of vehicles 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 operates 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 based on 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 ATM STRATEGIES

ATM strategies are often applied to the day-to-day operation of a facility. Incident management and work zone management are examples of applications of one or more ATM strategies to address specific facility conditions. Employer-based demand management is an example of private-sector applications for which 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” (5). An incident is “any non-recurring event . . . that causes a reduction in roadway capacity or an abnormal increase in traffic demand that disrupts the normal operation of the transportation system” (5). Such events include traffic crashes, disabled vehicles, spilled cargo, severe weather, and special events such as sporting events and concerts. ATM 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 safely moving traffic through the working area with as little delay as possible consistent with the safety of the workers, the safety of the traveling public, and the requirements of the work being performed. A transportation management plan (TMP) is a collection of administrative, procedural, and operational strategies used to manage and mitigate the impacts of a work zone project. The TMP may have three components: a temporary traffic control plan, a transportation operations plan, and a public information plan. The temporary traffic control plan describes control strategies, traffic control devices, and project coordination. The transportation operations plan identifies the demand management, corridor management, work zone safety management, and traffic and incident management and enforcement strategies. The public information plan describes public awareness and motorist information strategies (5). ATM strategies can be important components of a TMP.

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 regarding major construction projects, major incidents, and major 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 services and incentives may be implemented by the employer to facilitate employee ridesharing.

Employers may also 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.

3. METAMEASURES OF EFFECTIVENESS

INTRODUCTION

This section describes the need for meta-MOE for evaluating ATM strategies and provides some candidates for consideration. Meta-MOE are combinations of traditional HCM MOEs that have been computed over a range of demand and capacity conditions expected to occur in the real world.

NEED FOR META-MOEs

The analysis methodologies described elsewhere in the HCM are designed to produce a single set of performance results for a given set of input demands and computed capacities for a facility. Volume 1 provides discussions of the performance measures produced by the HCM for each system element in Chapter 4, Traffic Flow and Capacity Concepts; Chapter 5, Quality and Level of Service Concepts; and Chapter 7, Interpreting HCM and Alternative Tool Results. These HCM MOEs are, in essence, single point estimates of facility performance.

In addition, the HCM methodologies described elsewhere in this manual are often specifically oriented to ideal or near-ideal conditions, when weather, incidents, and other factors do not adversely affect capacity. HCM methodologies can be adapted to account for adverse effects on capacity, but their default condition is to exclude these effects.

ATM strategies, however, are designed to improve the performance of a facility over a range of real-world demand and capacity conditions, not just for a single forecast condition. Thus, the standard HCM performance measures and methodologies exclude the majority of the benefits of the dynamic and continuous monitoring and control of the transportation system, which is the objective of ATM.

A methodology is needed for computing traditional HCM MOEs (such as density, delay, speed, volume-to-capacity ratio, and queues) over a range of likely demand and capacity conditions and to combine them into one or more meta-MOEs that better characterize system performance under real-world conditions.

CANDIDATE META-MOEs

The evaluation of ATM performance requires MOEs that quantify the impacts of varying demands and capacities on performance. One way to achieve this is to develop methods for computing traditional HCM MOEs for varying combinations of demand and capacity conditions and to combine the results into various meta-MOEs for describing system performance with varying ATM strategies.

Various meta-MOEs may be considered by the analyst. These include

- Measures of central tendency, such as the mean, mode, or median of the HCM results;

ATM strategies 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.

The evaluation of ATM strategies requires performance measures that recognize the impact of less-than-ideal conditions on facility capacity.

- Measures of variation, such as the standard deviation or the variance of the HCM results;
- Measures of extreme results, such as the worst HCM results at the 85th, 90th, 95th, or 99th percentile;
- Measures of probability of failure and duration of failure, such as the probability of exceeding a target demand-to-capacity ratio for a given length of time, the probability of exceeding a target level of service, or the probability of exceeding some other agency-determined threshold MOE; and
- Measures of production, such as throughput, vehicle miles traveled, vehicles served, person miles traveled, or persons served.

For example, the analyst may choose to report for a traffic signal the mean delay, the standard deviation of delay, the 95th percentile delay, the probability of exceeding LOS E, the total number of vehicles served (throughput), or some combination of these measures. Each of these measures would be computed by using HCM methods for varying combinations of demand and capacity; the results would then be combined into meta-MOE's for the signal.

At present the interpretation and determination of what constitutes acceptable or unacceptable meta-performance is an open question that requires further research.

INDICES OF PERFORMANCE

While using many different MOE's can give a more complete picture of system performance, sometimes the data become too massive to comprehend, thus hindering rather than assisting the decision-making process. In such a case the analyst may find it desirable to combine one or more of the meta-MOE's of ATM performance into a single index. Performance indices are also useful when the analyst desires to optimize multiple dimensions of system performance. For example, signal timing optimization usually involves optimizing a weighted combination of stops and delays.

The formula in Equation 35-1 provides one example of many potentially useful methods for combining meta-MOE's into a meaningful index of performance. It applies an analyst-defined percentage weighting W to the average system performance and one minus that percentage to the 95th percentile system performance to yield an assessment of the robustness of the system. Other combinations that may be more useful to the specific needs of the analysis are also possible.

$$\text{Robustness Index} = W \times (\text{Average MOE}) + (1 - W) \times (95\% \text{ MOE})$$

where

Robustness Index = example composite index of system robustness,

W = relative weight (between 0 and 1), and

MOE = HCM MOE.

Equation 35-1

4. GENERAL EFFECTS

INTRODUCTION

This section presents basic information on what are considered to be the likely effects of specific ATM strategies on the demand, capacity, and performance of a roadway facility. The reader should recognize that there are currently many gaps in this basic information and that much of this discussion is based on a sparse set of research results.

ROADWAY METERING

Demand Effects

Roadway metering shifts some of the demand for the facility to other routes, other modes, and other times of day. Some of the demand remains, simply waiting for its turn to enter the facility. The demand effects are specific to the situation and the alternatives available.

Capacity Effects

Freeway on-ramp meters have been found to increase freeway mainline bottleneck capacity by 3% to 5% (6, 7). This effect is achieved by smoothing the microsurges of traffic from the on-ramp impacting the freeway and thereby delaying breakdown conditions at the bottleneck (8).

Greater increases have been observed in mainline vehicle throughput measured at various points upstream of a bottleneck.

Performance Effects

The primary performance effect of roadway metering is to delay or prevent the onset of mainline traffic congestion or breakdown. Average speeds of traffic within the metered facility can be significantly improved. The trade-off is increased delays for vehicles at the meters. A systemwide assessment is required to determine net system benefits.

Ramp meter evaluation studies (9) found that when freeway on-ramp meters were turned off

- Freeway volumes dropped 9%,
- Peak period freeway throughput declined 14%,
- Freeway travel times increased 22%,
- Freeway speeds dropped 7%, and
- Freeway crashes increased 26%.

Installing ramp meters would be expected to have the opposite results of those cited above (i.e., increased volumes, increased throughput, increased speeds, and fewer crashes). The performance benefits of roadway metering will vary with the specific conditions of each installation.

Estimation Methods

The HCM methodologies described elsewhere in this manual can estimate the performance effects of roadway metering. These methods, however, do not currently recognize the bottleneck capacity increases that are provided by freeway on-ramp metering.

Microsimulation models that have been properly calibrated to field conditions can be used to model the supply-side effects of ramp metering, mainline metering, and peak period ramp closures on freeway capacity and performance.

Demand models employing traffic assignment methods sensitive to metering (such as dynamic traffic assignment) are often required to estimate demand-side effects.

Capacity of Metered Freeway On-Ramps

A single-lane metered on-ramp that allows one vehicle per green can serve up to 900 veh/h. If two vehicles are allowed per green, then a single-lane metered on-ramp can serve from 1,100 to 1,200 veh/h (10).

A two-lane metered ramp provides a capacity of 1,600 to 1,700 entry vehicles per hour across the two lanes of the on-ramp (10).

These values are approximate. Actual capacity is determined by the maximum feasible metering rate, driver aggressiveness, and the ability of the freeway to absorb the ramp volume. While higher metering rates may be theoretically possible, practical constraints (such as driver compliance and reaction times) limit the maximum and minimum metering rates that may be employed.

CONGESTION PRICING

Demand Effects

Congestion pricing shifts some of the demand to other lanes, other routes, other modes, and other times of day. Some of the demand remains, and drivers will simply pay the toll. The demand effects are specific to the pricing policy, the travelers' value of time, and the alternatives available.

If the pricing policy is to maintain demand on the facility within a target range, then the demand for the facility is the known value (within the target range), and the unknown value is the price.

If the pricing policy is to maintain a minimum speed on the facility, then the equivalent maximum operating volume range is on the order of 1,600 to 1,700 veh/h/ln (11). These values appear to be appropriate for sustained minimum average operating speeds of 40 to 45 mi/h for a single HOT lane. Lower flow values may be necessary to achieve higher average sustainable minimum operating speeds. Higher flow values may be achievable for multilane HOT lane facilities.

Capacity Effects

Congestion pricing, by spreading out the peaking of facility demand, can enable the facility to move more vehicles over the course of a peak period.

Performance Effects

Congestion pricing can result in significant reductions in delay for the priced facility. A study of the CA-91 express lanes (12) found the following:

- Overall traffic volumes on CA-91 increased by 15% in the first 18 months after express lanes were added to the facility.
- Peak-direction travel times for express lane users were reduced from 70 min before the express lanes opened to 12 min after the lanes opened. Non-express lane users also experienced a significant reduction in peak-direction travel times, from 70 min to 30 min. However, increasing demand over the following 18 months gradually eroded much of that savings for the non-express lane users.
- The express lanes did not cause a significant change in vehicle occupancies.

Estimation Methods

The demands for a priced facility can often be reasonably estimated from the pricing policy if the pricing policy sets a minimum operating speed threshold.

A demand model and the value of time are required for predicting systemwide demand effects, for evaluating the demand effects of specific pricing schedules, and for estimating revenues.

At present the HCM does not provide methodologies for evaluating many of the specific geometric configurations currently being used to implement HOT lanes. Capacity and operation analysis methods are lacking for single-lane facilities where faster vehicles are unable to pass a slower vehicle in the lane. The entry and exit points for barrier-separated facilities are also not explicitly covered by HCM methodologies, although the methodologies may be adaptable to those conditions.

Microsimulation models, properly calibrated to field conditions, may be used to evaluate the operation of congestion-priced facilities.

TRAVELER INFORMATION SYSTEMS

Demand Effects

Traveler information systems shift some of the demand to other routes, other modes, and other times of day. Some of the demand will remain. The demand effects are specific to the situation and the alternatives available.

Capacity Effects

Traveler information systems, by redirecting demand, can postpone or avoid the onset of traffic congestion, thus yielding the throughput benefits typical of such conditions.

Performance Effects

Reductions in demand due to redirected traffic and the postponement of traffic breakdowns can result in net performance improvements. Work zone management programs in Texas and Washington, D.C., employing traveler information systems as part of an overall ATM strategy to improve traffic operations within work zones have achieved demand diversions of between 10% and 50% (13).

Estimation Methods

The HCM does not provide methodologies for directly assessing the performance effects of traveler information systems. However, if an estimate of the changed demand levels can be obtained, then the HCM methodologies can be applied to estimate system performance.

Some microscopic and mesoscopic simulation models provide route choice algorithm parameters that can be adjusted to account for different levels of traveler information penetration and compliance in the vehicle fleet.

Demand-forecasting tools have not been typically used to predict the demand effects of traveler information systems, but they may be adaptable for that purpose. The analyst should verify how the demand-modeling software treats traveler information within its route-choice process.

MANAGED LANES

Demand Effects

Managed lanes change the nature and quantity of demand for a facility. Capacity increases due to the addition of managed lanes tend to draw more demand to the facility. Managed lanes can cause modal and temporal shifts in demand for the facility by making certain modes of travel subject to less delay than others for certain times of the day.

Capacity Effects

The addition of new managed lanes to a facility generally increases the facility's overall capacity.

For managed lanes that are barrier separated from the rest of the facility, weaving and merging at the entry and exit points may be a significant traffic operations issue. The weaving capacity of the entry and exit points may control the overall facility capacity (14). The capacity would be affected by mainline configuration, access design, and traffic patterns.

For reversible lanes, significant capacity and performance benefits may be lost when the lanes must be closed in their entirety so that the flow direction can be reversed.

Performance Effects

The addition of new managed lanes to a facility generally improves facility performance for all users. Vehicles eligible to use the HOV lanes will experience significant reductions in delay. Single-occupant vehicles will also experience

reduced delays because of the additional gaps in traffic opened up when HOVs move from the mixed-flow lanes to the HOV lanes.

A Federal Highway Administration inventory of HOV facilities in the United States (15) found that HOV lane users experienced travel time savings of between a few seconds per mile to 6 min/mi or more, depending on the extent and severity of congestion on the adjacent mixed-flow lanes.

Estimation Methods

The HCM methodologies described elsewhere in this manual are not validated or calibrated for the special conditions posed by managed lanes or shoulder lanes; however, it may be possible to adapt the HCM methods with the proper choice of parameters.

Microsimulation tools that are properly calibrated and validated for existing field conditions can provide performance information for most managed lane configurations. Special calibration of these models may be required to model shoulder lanes adequately.

Maximum Target Flow Rates for HOV and Bus Lanes

HOV lanes start to experience a noticeable degradation of performance (speeds dropping to 45 mi/h or less) at flows of 1,200 to 1,500 veh/h/ln (16). The following general maximum operating thresholds for different types of HOV facilities are based on national experience (17):

- Separate right-of-way, bus only: 800 to 1,000 veh/h/ln
- Separate right-of-way, HOV: 1,500 to 1,800 veh/h/ln
- Freeway, exclusive two directional: 1,200 to 1,500 veh/h/ln
- Freeway, exclusive reversible: 1,500 to 1,800 veh/h/ln
- Freeway, concurrent flow: 1,200 to 1,500 veh/h/ln
- Freeway contraflow, bus only: 600 to 800 veh/h/ln
- Freeway contraflow, HOV: 1,200 to 1,500 veh/h/ln
- HOV bypass lanes: 300 to 500 veh/h/ln

Note that the above maximum operating thresholds are not capacities, but rather values above which an undesirable degradation in lane speeds is likely to occur. These values generally apply to single-lane operation. Multiple lanes may achieve higher operating thresholds.

The *Transit Capacity and Quality of Service Manual* (18) points out that the capacity of exclusive bus lanes on freeways is dictated either by the capacity of any off-line bus stops along the bus lane section or by the bus stops located after the end of the bus lane. Thus the capacity of a bus lane on a freeway is generally meaningless.

TRAFFIC SIGNAL CONTROL

Demand Effects

Traffic signal control, by controlling capacity and delay, can draw more demand to the facility or can shift some of the demand to other routes, other modes, and other times of day. The demand effects are specific to the conditions and the alternatives available.

Capacity Effects

Traffic signal control directly affects capacity through the formula shown in Equation 35-2.

$$c = (g/C) \times s$$

Equation 35-2

where

c = capacity (veh/h),

g/C = effective green time per traffic signal cycle length, and

s = saturation flow rate (veh/h).

ATM strategies that modify the heavy-vehicle mix can influence the saturation flow rate, and those strategies that affect peaking can influence the peak 15-min volume-to-capacity ratio. Otherwise, signal control affects capacity primarily through the g/C ratio.

Performance Effects

The effects of advanced signal timing applications vary according to the quality of the signal timing plans in place prior to implementation. The percentage change can be small if the original plan was of high quality and frequently maintained and updated.

On average, improvements to signal timing plans have been found to reduce average peak period facility travel times by 8% to 25% and to reduce delay in the 15% to 40% range (19).

Estimation Methods

The HCM methodologies described in Volume 3 can be used to evaluate the capacity and performance effects of the optimization and coordination of fixed-time and traffic-actuated signal systems. These methods, however, are not suitable for evaluating signal preemption, signal priority, or traffic-adaptive and traffic-responsive control strategies.

Most commonly available microsimulation tools are appropriate for evaluating signal control strategies. Their ability to model advanced control strategies (traffic-responsive and -adaptive controls) varies according to the sophistication of the signal controller emulator built into the microsimulation tool.

SPEED HARMONIZATION

Demand Effects

The available literature on speed harmonization does not provide information on its demand effects. If speed harmonization does not significantly change average travel speeds for the facility, then it would not be expected to affect demand significantly. Improved operations and reliability associated with speed harmonization might draw demand to the facility.

Capacity Effects

Speed harmonization is designed to reduce the frequency of incidents caused by sudden decelerations in the traffic stream and to postpone the onset of congestion. These effects will in turn influence the facility capacity.

Some early studies found that speed harmonization could increase the total capacity of a freeway by 10%, but other studies have found no effects. More recent studies in Germany suggest that the primary capacity impact of speed harmonization is on the variation of capacity. Capacity variance may be reduced 50% while average capacity is increased on the order of 3% (20). Speed harmonization on the Netherlands' Motorway Control System was found to increase vehicle throughput by 3% to 5% (21).

Performance Effects

Studies to date suggest clear benefits in terms of collision reductions, which translate into better reliability.

The literature is less clear on the performance effects of speed harmonization. Speed harmonization often results in lower average speeds, which are counterbalanced to some extent by improved reliability in travel times. These counterbalancing effects can result in net positive or negative travel time benefits, depending on circumstances. For example, a freeway management plan that included speed harmonization on the M25 controlled motorway in the United Kingdom was found to result in a 10% reduction in injury collisions, no net change in travel times, and a 9% reduction in time the facility was operating in flow breakdown conditions (speeds under 25 mi/h) (22).

Estimation Methods

The HCM methodologies described elsewhere in this manual do not recognize the potential capacity effects of postponing breakdown or the reliability effects of reduced incident frequency.

Most commonly available microsimulation models will show the performance changes of reducing speed variance and shocks in the traffic stream, but using them to model the reliability and delay effects of reduced incidents is more difficult. A methodology is required to estimate the reduced probability of incidents for a given speed harmonization policy.

5. REFERENCES

1. Federal Highway Administration. *Ramp Management and Control: A Primer*. FHWA-HOP-06-080. Washington, D.C., 2006.
2. Federal Highway Administration. *Technologies That Complement Congestion Pricing: A Primer*. FHWA-HOP-08-043. Washington, D.C., 2008.
3. Federal Highway Administration. *Managed Lanes: A Primer*. FHWA-HOP-05-031. Washington, D.C., 2005.
4. Federal Highway Administration and University of Florida. *National Signal Timing Optimization Project Summary Evaluation Report*. 1982.
5. Balke, K. *Traffic Incident Management in Construction and Maintenance Work Zones*. FHWA-HOP-08-056. Federal Highway Administration, Washington D.C., 2009.
6. Levinson, D., and L. Zhang. Ramp Meters on Trial: Evidence from the Twin Cities Metering Holiday. *Transportation Research Part A: Policy and Practice*, Vol. 40, No. 10, 2006, pp. 810–828.
7. Zhang, L., and D. Levinson. Ramp Metering and the Capacity of Active Freeway Bottlenecks. *Transportation Research Part A: Policy and Practice*, 2004.
8. Cassidy, M. J., and J. Rudjanakanoknad. *Empirical Study of Ramp Metering and Capacity*. UCB-ITS-RR-2002-5. Institute of Transportation Studies, University of California, Berkeley, 2002.
9. Cambridge Systematics. *Twin Cities Ramp Meter Evaluation*. Oakland, Calif., 2001. <http://www.dot.state.mn.us/rampmeter/background/finalreport.html>. Accessed Nov. 16, 2009.
10. Jacobson, L., J. Stribiak, L. Nelson, and D. Sallman. *Ramp Management and Control Handbook*. FHWA-HOP-06-001. Federal Highway Administration, Washington, D.C., 2006.
11. Perez, B., and G. C. Sciara. *A Guide for HOT Lane Development*. FHWA-OP-03-009. Federal Highway Administration, Washington, D.C., 2003.
12. Sullivan, E. C., and J. El Harake. California Route 91 Toll Lanes: Impacts and Other Observations. In *Transportation Research Record 1649*, Transportation Research Board, National Research Council, Washington, D.C., 1998, pp. 55–62.
13. Federal Highway Administration. *Benefits of Using Intelligent Transportation Systems in Work Zones: A Summary Report*. FHWA-HOP-08-021. Washington, D.C., 2008.
14. Wolshon, B., and L. Lambert. *NCHRP Synthesis of Highway Practice 340: Convertible Roadways and Lanes*. Transportation Research Board of the National Academies, Washington, D.C., 2004.
15. Chang, M., J. Wiegmann, and C. Billotto. *A Compendium of Existing HOV Lane Facilities in the United States*. FHWA-HOP-09-030. Federal Highway Administration, Washington, D.C., 2008.

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

16. Turnbull, K. F. *Potential Impact of Exempt Vehicles on HOV Lanes*. FHWA-HOP-05-058. Federal Highway Administration, Washington, D.C., 2005.
17. Texas Transportation Institute; Parsons Brinckerhoff Quade and Douglass, Inc.; and Pacific Rim Resources. *NCHRP Report 414: HOV Systems Manual*. Transportation Research Board, National Research Council, Washington, D.C., 1998.
18. Kittelson & Associates, Inc.; KFH Group, Inc.; Parsons Brinckerhoff Quade & Douglass, Inc.; and K. Hunter-Zaworski. *TCRP Report 100: Transit Capacity and Quality of Service Manual*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2003.
19. Srinivas, S. The Benefits of Retiming Traffic Signals. *ITE Journal*, Vol. 74, No. 4, 2004, pp. 26–30.
20. Kittelson & Associates, Inc. *SHRP2 C05 Working Paper #2: Inventory of Existing Strategies and Tactics*. Portland, Ore., 2009.
21. Neudorff, L. G., J. E. Randall, R. Reiss, and R. Gordon. *Freeway Management and Operations Handbook*. FHWA-OP-04-003. Federal Highway Administration, Washington, D.C., 2003.
22. Allaby, P., B. Hellenga, and M. Bullock. Variable Speed Limits: Safety and Operations Impacts of a Candidate Control Strategy for an Urban Freeway. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 8, No. 4, 2007, pp. 671–680.