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Operating Guidelines for TxDOT Ramp Control Signals

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DISCLAIMER

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Introduction

The Texas Department of Transportation (TxDOT) currently maintains a *Traffic Signals Manual*. Originally published in 1999, this manual provides a guide and reference for handling requests for traffic signals on the designated State Highway System, including installations financed by federal funds and installed on the numbered State Highway System. It describes the steps necessary for installing a traffic signal, from project inception through construction and final disposition of records. It contains five chapters: Introduction, Requests for Traffic Signal, Traffic Studies, Operational Considerations, and Traffic Signal Projects. It also contains two appendices: one that contains the forms necessary to warrant and install a traffic signal on TxDOT roadways and another for determining the need for traffic control at school crossings. The manual is available online at http://onlinemanuals.txdot.gov/txdotmanuals/tff/index.htm.

The following information is a product of TxDOT Research Project 0-5294 *Warrants for Installing and Operating Ramp Metering.* It provides guidelines for installing, operating, and maintaining ramp control signals on TxDOT roadways. These guidelines were written with the intent of becoming a new chapter in TxDOT's *Traffic Signals Manual*.

Chapter 6

Ramp Control Signals

Contents

This chapter contains the following sections:

Section 1

Introduction

What is a Ramp Control Signal?

A *Ramp Control Signal* (or *Ramp Meter*) is a highway traffic control signal that has been installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection (*1*). The intent of the ramp control signal is to control the rate of release of vehicles entering the freeway from the ramp to one or two vehicles at a time. By controlling the rate at which vehicles are allowed to enter the freeway, the ramp control signals are intended to accomplish the following objectives:

- ♦ To promote a more consistent and uniform flow of traffic entering the freeway by:
  - managing demand allowed to enter the freeway and
  - breaking up the platoons of vehicles released from upstream traffic signals;
- ♦ To promote more efficient use of the existing freeway capacity by:
  - smoothing traffic flow in merge areas on the freeway and
  - reducing the potential for crashes and erratic maneuvers in the merge area.

Benefits of Ramp Control Signals

The potential benefits to be derived by deploying ramp control signals in a freeway corridor include the following (*2*):

- ♦ Improved system operation:
  - increased vehicle throughput,
  - increase vehicle speeds, and
  - improved use of existing capacity;
- ♦ Improved safety:
  - reduction in the number of crashes and crash rate in merge zones, and
  - reduction in the number of crashes and crash rate on the freeway upstream of the ramp/freeway merge zones;
- ♦ Reduced environmental effects:
  - reduced vehicle emissions, and
  - reduced fuel consumption;
- ♦ Promotion of multi-modal operations.

References

1. *Texas Manual on Uniform Traffic Control Devices for Streets and Highways. Part 4. Highway Traffic Signals.* Texas Department of Transportation. 2006. Available at ftp://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/gov/devices/2006part4.pdf

2. L. Jacobson, J. Stribiak, L. Nelson, and D. Sallman. *Ramp Management and Control Handbook.* Report No. FHWA-HOP-06-001. U.S. Department of Transportation, Federal Highway Administration. January 2006. Available at http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/pdf/rm_handbook.pdf

Section 2

Approval Process

Introduction

The process of approving the installation of a ramp control signal is similar to that used to approve the installation of an intersection traffic control signal. Requests for the installation of a ramp control signal can be initiated internally by district staff or externally from the public. Regardless of the source of the request, the same process should be used to assess the need for a ramp control signal. A ramp control signal should only be installed after completing a traffic engineering investigation.

TxDOT Approval Process

The following process should be used to assess the need for a ramp control signal at a particular entrance ramp location:

1. The district traffic operations section should conduct a traffic engineering study to determine if traffic operations on the freeway and in the ramp would benefit from the installation of a ramp control signal. Criteria for conducting this assessment are provided below.

2. If the traffic engineering study suggests that traffic operations on the freeway could potentially be improved through the installation of one or more ramp control signals, the district then decides, based on engineering judgment, if installation of the ramp control signal would be in the best interest of the motoring public. If, based on engineering judgment, it is decided that the motoring public would not be best served through the installation of a ramp control signal, then the district traffic section should consider other freeway and ramp control strategies for correcting operations and safety deficiencies (if any) at the ramp location.

3. If a ramp control signal is deemed appropriate, the district traffic operation section should forward its recommendations and a Ramp Control Signal Authorization form (see Appendix A) to the district engineer for final approval and signature.

4. If the ramp control signal is approved by the district engineer, the district then should initiate preparation of the plan, specifications, and estimates (PS&E) needed to construct and install the ramp control signal. Also, upon approval of the district engineer, the district traffic operations section should forward a signed copy of the Ramp Control Signal Authorization form to the Traffic Operations Division.

The decision to install a ramp control signal rests with each district, in consultation with the Traffic Operations Division. District staff should contact the Traffic Operations Division for assistance in applying the ramp installation criteria or in completing the Ramp Control Signal Authorization form.

Section 3

Installation Criteria

Introduction

Prior to initiating the installation of a ramp control signal, an engineering study should be performed to assess the need for and potential benefits and impacts to be derived from the installation. The engineering study should include an assessment of the physical and traffic conditions that exist not only on the highway facility, but also the ramps, ramp connections, and surface streets anticipated to be affected by the proposed ramp control signal. The traffic engineering study should not be limited to the immediate vicinity of the ramp in question, but should also consider impacts upstream and downstream of the study section.

Criteria

Primary Criteria. Chapter 4H. Traffic Control Signals for Freeway Entrance Ramps of the *Texas Manual on Uniform Traffic Control Devices* (*TMUCTD*) indicates the following (*1*):

"Freeway entrance ramp control signals are sometimes used if controlling traffic entering the freeway could reduce the total expected delay to traffic in the freeway corridor, including freeway ramps and local streets, and if at least one of the following conditions is present:

A. Congestion recurs on the freeway because traffic demand is in excess of the capacity, or congestion recurs or a high frequency of crashes exists at the freeway entrance because of inadequate ramp merging area. A good indicator of recurring freeway congestion is freeway operating speeds less than 50 mph occurring regularly for at least a half-hour period. Freeway operating speeds less than 30 mph for a half-hour period or more would indicate severe congestion.

B. Controlling traffic entering a freeway assists in meeting local transportation system management objectives identified for freeway traffic flow, such as the following:

1. Maintenance of a specific freeway level of service.

2. Priority treatments with higher levels of service for mass transit and carpools.

3. Redistribution of freeway access demand to other on-ramps.

C. Predictable, sporadic congestion occurs on isolated sections of freeway because of short-period peak traffic loads from special events or from severe peak loads of recreational traffic."

Traffic Considerations. TxDOT Research Project 0-5294 found that ramp control signals resulted in significant improvements in freeway running speeds when the following traffic conditions existed (as compared to freeway operating without ramp control signals):

- traffic flow rate on the entrance ramp exceeds 300 vph,
- average traffic flow rate of the two right-most lanes exceeds the thresholds shown in Figure 3-1, and
- the combined traffic flow rate in the rightmost freeway lane plus the flow rate on entrance ramp exceeds the thresholds shown in Figure 3-2.

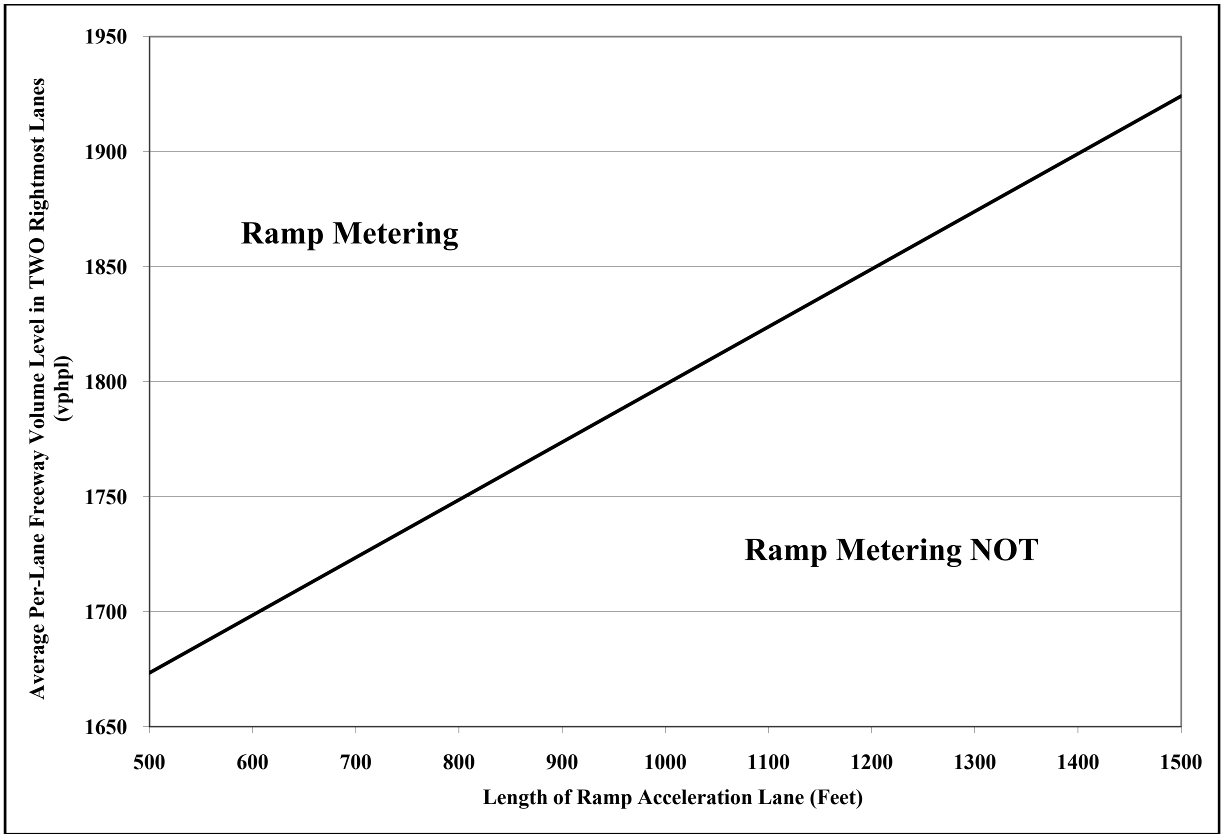

Figure 3-1. Minimum Freeway Flow Rate for Implementing Ramp Control Signal at an Isolated Freeway Entrance Ramp.

Safety Considerations. Freeway entrance ramp control signals may also be appropriate when "*a high frequency of crashes exists at the freeway entrance because of inadequate ramp merging area.*" TxDOT Research Project 0-5294 suggests the following criteria be used to assess the need for a ramp control signal:

- The rate of crashes in the immediate vicinity of the ramp exceeds the mean crash rate for comparable sections of freeway metropolitan area.

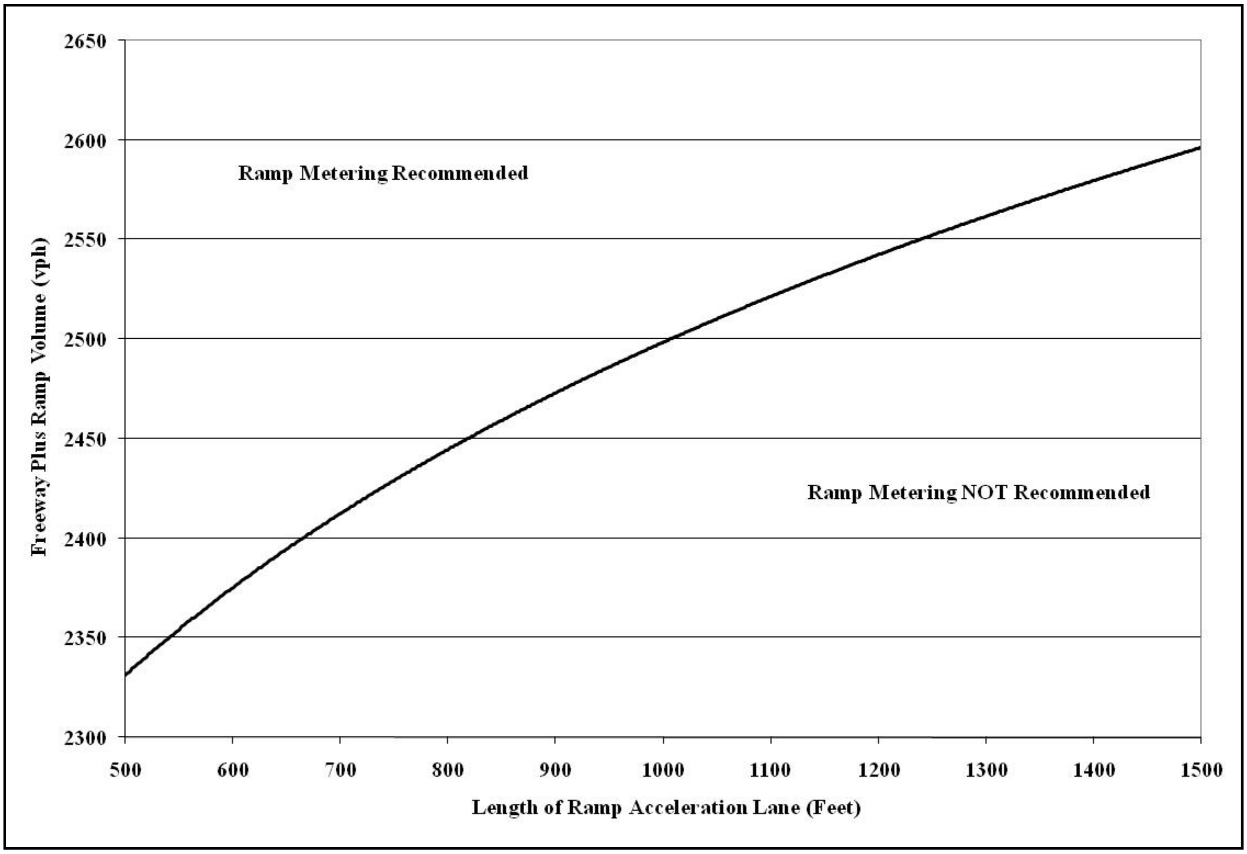

Figure 3-2. Minimum Combined Freeway Plus Ramp Flow Rate for Implementing Ramp Control Signal at an Isolated Freeway Entrance Ramp.

- ♦ The primary cause of the majority of crashes can be attributed to congestion in the merge area.
- ♦ The ramp length will permit a vehicle starting from a stop to reach the prevailing speed of the freeway traffic in the merge area so as to prevent an unacceptable speed differential (see Appendix A).
- ♦ Sufficient storage length exists upstream of the ramp control signal to prevent queues from impeding operations on the frontage road or surface street intersection (see Appendix A).

Factors Influencing the Installation Decision

In addition to comparing the existing conditions to the criteria discussed above, the decision to install a ramp control signal should also consider the following factors.

Characteristics of Traffic Stream. Because of the poor operating characteristics of heavy vehicles, ramp control signals should not be used where a substantial amount of traffic entering the ramp is trucks or other types of heavy vehicles during the hours of operation or where heavy vehicles are restricted to specific lanes that may conflict with entering traffic.

Ramp control signals may not be appropriate near a port, major truck stops, or warehouse/industrial park areas.

Diversion. The installation of a ramp control signal has the potential to divert traffic from the freeway to adjacent arterial streets. At locations where ramp control signals have been installed, motorists, particularly those who are using the freeway for short trips where the wait time at the ramp may exceed the additional travel time on adjacent routes, may elect to bypass the queues that form at the ramp locations and either remain on the frontage roads or use alternate routes.

The amount of ramp traffic that can be expected to divert to other facilities is influenced by following conditions:

- the number of available routes to accommodate diverting traffic, and
- the available capacity on those alternate routes.

In assessing whether or not to install a ramp control signal, the following criteria are suggested:

- If the amount of anticipated diversion on adjacent streets is expected to exceed a predetermined threshold. A suggested threshold level is 25 percent increase in traffic volumes on the adjacent roadways.[1]
- If the traffic operations on the alternate routes are expected to be degraded substantially by the increase in diverted traffic.
- If one or more of the potential alternate routes diverts traffic through an adjacent neighborhood or other sensitive location.

Equity. Equity is often cited as an argument against installing ramp control signals. Equity issues arise from the perception that ramp control signals favor suburban motorists who make longer trips than those who live in the immediate area of the ramp, who make shorter trips. The perception is based on the assumption that individuals already on the freeway are not delayed by the ramp control signal. Issues of equity tend to be more pronounced in areas that lead to a core destination (such as a central business district) where those entering the freeway closer to the destination have proportionally unfair commutes when comparing travel time against travel distance.

[1] After ramp meters were installed on I-5 in Portland, traffic volumes on adjacent streets were closely monitored to determine if volumes had increased by more than 25 percent (a predetermined threshold that was agreed upon by the state and local city officials). If volumes had exceeded this 25 percent threshold, the deployed ramp meters had to be either removed or adjusted to cut the increased volumes to below 25 percent.

Strategies that have been employed to address equity issues include the following:

- ♦ Initially operate the ramp control signal in the outbound direction to eliminate the city-suburban equity problem.
- ♦ Implement more restrictive metering rates farther away from the central business district.

Emissions on Ramps. While ramp control signals have the potential to reduce vehicle emissions and fuel consumption on the freeway, these reductions are offset by increases in emissions and fuel consumption for vehicles waiting to enter from the ramp. Generally, vehicles accelerating from a stop consume more fuel and emit more pollutants than vehicles that are already moving. Careful consideration should be given to whether ramp control signals are justified when traffic on the freeway is operating at or close to free-flow speeds.

Arterial Impacts. During times of high traffic demand, sufficient capacity on the ramp may not exist to accommodate all waiting vehicles. Queuing traffic can have a significant impact on the way the frontage roads and parallel arterials operate. When considering a new ramp control signal, the following should be assessed:

- ♦ Determine if sufficient distance exists between the ramp and upstream intersection to store queued traffic. Care should be taken to ensure that traffic queues from the ramp control signal do not spill back into an upstream intersection.
- ♦ Determine if available storage space is utilized equitably between all movements wanting to utilize the ramp. Assess whether any one particular movement, such as free right-turns from the upstream intersection (or turning traffic from a U-turn bay) will utilize more than its “fair share” of the available storage capacity.
- ♦ Determine if sufficient weaving distance exists between the back of the queue at the ramp control signal and entry points of approaching movements. This includes heavily utilized driveways, free right-turns from signalized intersections, or traffic entering from a U-turn bay.
- ♦ Determine if sufficient stopping sight distance exists for vehicles traveling at high speed on the frontage road approaching the end of queue.

Public Perception and Institutional Support. Ramp control signals should not be installed where poor public perception or institutional support exist. Poor public perception often stems from the fact that the associated benefits of ramp control signals are not readily visible. Poor institutional support can develop where ramp controls signals are poorly operated and maintained. Districts need to be proactive in disseminating information to the public and collecting quantitative benefit information about the controlled ramp operations. Prior to initiating the installation of ramp control signals, a well devised and executed public information campaign is needed to build public support.

Geometric Conditions. Geometric constraints may prevent or limit the effectiveness of ramp control signals. The following describes several situations where installing a ramp control signal should be avoided:

- Add-lanes – ramp control signals may not be appropriate when an entrance ramp adds a new lane on the freeway. New lane additions generally eliminate the need for vehicles to merge into the freeway.
- Closely spaced ramps – ramps that are too closely spaced (less than 1 mile apart) may not offer the merging distance needed for vehicles to safely enter and exit the freeway at freeway speeds. Ramp control signals can exacerbate this situation by creating a speed differential upstream from entrance ramps and downstream from exit ramps.
- Sight distance limitations – sight distance limitations on ramps can be created by the curvature of the ramp, the approach grade of the ramp and/or freeway lanes, or the presence of sight obstructions (e.g., vegetation, bridge columns, overhead structures, etc.).

Data Requirements

The decision to install a ramp control signal should be based on actual, measured traffic and geometric conditions. While it may be appropriate to install the infrastructure (conduit, pull-boxes, communications, etc.) to support ramp control signals in new freeway construction or reconstruction, the decision to install and operate ramp control signals should not be based on future or projected traffic conditions.

The following data are required to complete an assessment of the need for a ramp control signal.

Geometric Conditions. The following information about the geometry of the freeway-ramp merge area is needed in completing an assessment of the need for a ramp control signal:

- the number of lanes on the freeway section upstream and downstream of the proposed ramp control signal location,
- the number of lanes and width of the ramp,
- the length of the acceleration lane of the ramp merge area (measured from the nose of the gore area to the beginning of the taper to end the acceleration lane),
- the grade of the ramp approaching the freeway merge area,
- the length of the ramp (measured from the beginning of the ramp on the frontage road to the gore of the area on the freeway),
- the distance from the upstream arterial conflict point (either the intersection or the U-turn bay) to the beginning of the entrance ramp,

- the presence of any sight distance restrictions (trees, buses, retaining walls, bridge columns, etc.), and
- the free-flow and prevailing speed of both the traffic on the ramp and on the freeway.

Vehicle Counts at Site. The traffic count should include the number of vehicles in each lane of the freeway upstream of the ramp location and the number of vehicles entering the freeway on the ramp. Ideally, a full week of data (Monday through Friday) should be collected, but at a minimum, traffic count data from both the freeway and the ramp should be made from three consecutive, "representative days" (defined later). Furthermore, under ideal conditions, data should be collected for 24 hours during each data collection period, but at a minimum traffic counts should be made from at least 1 hour before the AM peak period to 1 hour after the PM peak period. Traffic count data should be recorded for each quarter hour (i.e., 15-minute interval) for the duration of the count. While it is not essential to quantify the number of heavy vehicles on both the freeway and entrance ramp, it is important to note whether a significant proportion of both the freeway and the ramp traffic streams can be classified as heavy vehicles.

Whenever possible, traffic count data should be collected from "representative days." A representative day is one in which traffic conditions generally reflect a typical day on the freeway. Generally speaking, a representative day is normally an average midweek day. Whenever possible, data should be collected on days free from unusual traffic events, such as incidents or collisions.[2] In addition to incident-free data, avoid using traffic count data that includes any of the following conditions:

- days on which weather has a significant impact on traffic operations,
- near major traffic generators or retail areas during major traffic events or holidays,
- near major school holidays (such as spring, fall, and winter breaks, or during summer months), or
- days which are classified as federal or state holidays.

Collision (or Crash) Information. Crash information in the immediate vicinity of the ramp location should be obtained for a minimum of 1 year and preferably 3 years prior to the study period. Crash information can be obtained from traditional TxDOT sources. In those locations where accident and collision information are routinely collected as part the routine logging of incident information, these logs can be used as a substitute for actual collision records.

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[2] Incident conditions upstream or downstream of the study location can significantly alter freeway counts in the study location. Incidents on adjacent facilities can also significantly alter typical travel patterns on a freeway. It is critical that the individual doing the analysis have a clear understanding of the presence and impacts of any incident that occurs during the data collection phase and whether that incident has a significant impact on traffic operations in the analysis section.

References

1. *Texas Manual on Uniform Traffic Control Devices for Streets and Highways. Part 4. Highway Traffic Signals.* Texas Department of Transportation. 2006. Available at ftp://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/gov/devices/2006part4.pdf

Section 4

Operating Philosophies

Introduction

Once the decision to install a ramp meter has been made, the next step in the process is to determine how the ramp meter shall operate. In selecting an operating strategy, the practitioner must decide the following:

- ♦ Will the meter be operated locally or as part of a system?
- ♦ Will the meter operate in a pre-timed or traffic responsive manner?
- ♦ Will the meter be intended to restrict the amount of traffic from entering the freeway? If so, how are queues on the ramp going to be managed?

This section contains guidelines on selecting an operating strategy for TxDOT ramp meters.

Local versus System-Wide Metering

Like traffic signals at intersections, ramp meters can operate either in isolation from one another (generally called "local" control) or as part of a system (generally called "system" control). Similar to traffic signals, local control implies that the ramp meter operates independently from other ramp control treatments upstream or downstream of the ramp. Generally, local control is used to operate meters at individual, nonadjacent ramps where problems are isolated and where no need exists to "coordinate" the effects of multiple ramps.

System control is generally used in more complex situations where congestion or other operational problems are dispersed over multiple ramps or locations. With system-wide metering, the practitioner takes into account conditions beyond the immediate proximity of the ramp to include multiple ramps upstream and downstream of the problem location. With system-wide metering, the primary emphasis is on improving operations from a broader "systems" perspective, including a freeway segment, an entire corridor, or several freeway corridors where problems extend from ramp to adjacent ramp.

Figure 4-1 provides the decision process for determining whether to operate a ramp meter under local or system control.

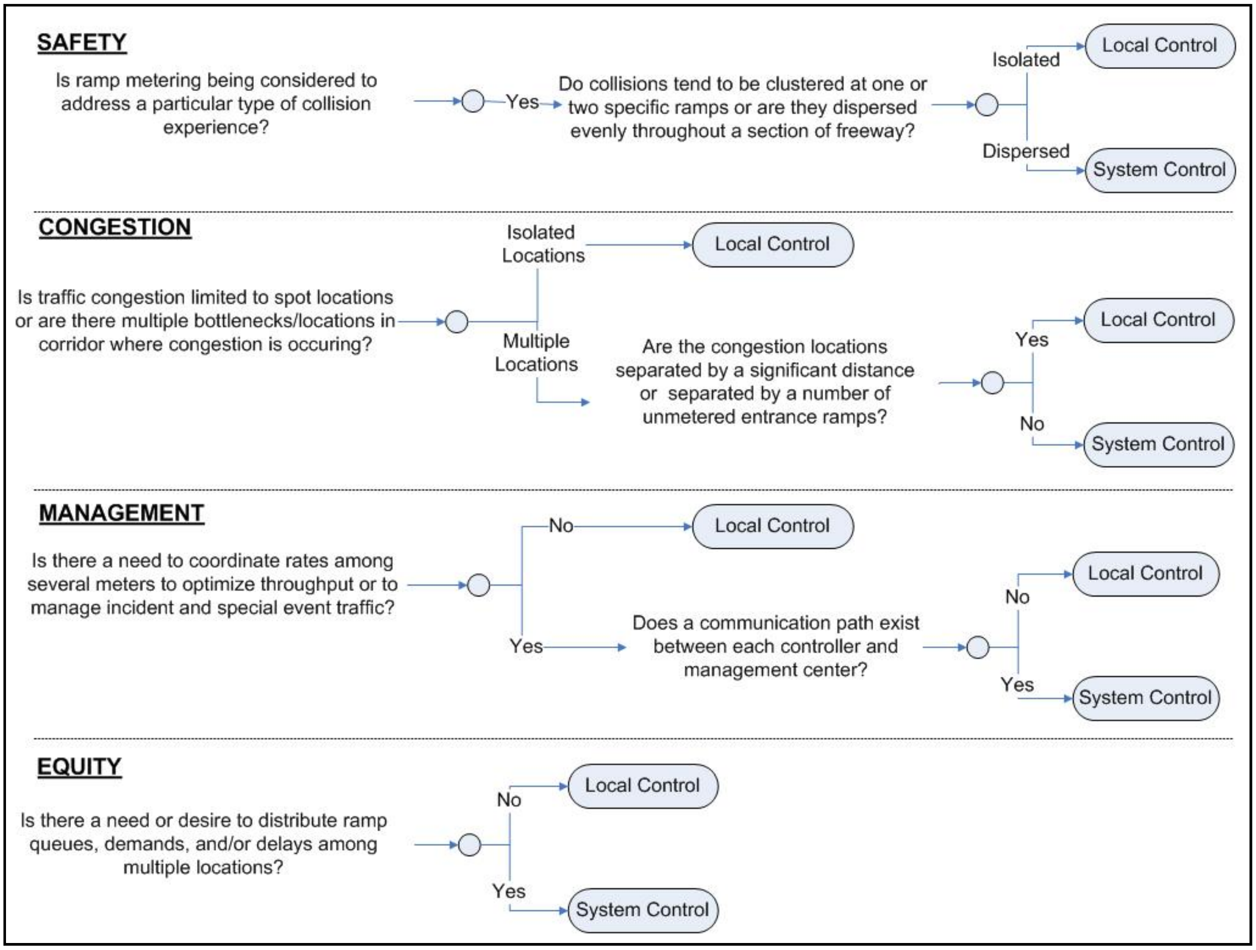

Figure 4-1. Guidelines for Determining Whether Ramp Meters Should Be Operated in a Local or System Perspective.

Pre-Timed versus Traffic Responsive Control

Pre-Timed Control. Pre-timed control represents the most basic level of control, as it is often the least expensive and easiest form of ramp control to set up. Similar to a pre-timed traffic signal, the ramp control signal is set up to operate using historical data. Activation of the ramp control signals and the release rate (or metering rate) is selected based on time-of-day patterns. Situations where pre-timed ramp control signals may be appropriate are as follows:

- where detectorization of the freeway and ramp and communications to a traffic management center do not currently exist or can be installed as part of the installation,
- where recurring congestion or localized safety issues can be reduced by simply breaking up platoons of traffic entering the freeway,
- where freeway and ramp traffic arrival patterns are predictable from day-to-day, and

- at ramps located inside construction zones where temporary control is needed to assist flow on the freeway[1].

Traffic Responsive. Traffic responsive ramp control signals use traffic sensors to calculate the rate at which vehicles enter the freeway. Traffic responsive mode is equivalent to an intersection traffic signal operating in an actuated mode. Local traffic responsive mode refers to a mode of operation of the ramp control signal where only traffic conditions in the immediate vicinity of the ramp are considered in making operational decisions. The control objective with local traffic responsive is to optimize operations in the immediate vicinity of the ramp. Local traffic responsive control is best suited when multiple ramps are operated independently of one another.

Traffic responsive control is routinely used where freeway sensors are used to either 1) begin (or end) operation and/or 2) select ramp control signal cycle rate (i.e., the metering rate). In this type of option, traffic on the freeway must exceed a particular threshold (usually an occupancy threshold) in order for the ramp meter to begin cycling. Different metering rates can also be assigned for use during different congestion levels on the freeway. This operation is similar to a traffic responsive operating mode at a traffic signal where different cycle lengths are selected based on approach demand.

System-wide traffic responsive operation describes a type of operation where multiple ramp control signals are operated collectively as a system to optimize traffic flow along a stretch of freeway (as opposed to a specific ramp or point on the freeway). With system-wide traffic responsive operations, detectorization of both the freeway and the ramps are required and communications to a “master” or centralized ramp meter computer are required. System-wide traffic responsive control currently represents the highest level of ramp control.

Most TxDOT ramp control signals are designed to operate in a local traffic responsive mode.

Restrictive versus Non-Restrictive Control

Restrictive Control. Restrictive ramp control refers to a mode of operation where the ramp control signal is used to restrict the amount of ramp demand that is allowed to enter the freeway. Restrictive control is used in an attempt to limit the demand from exceeding the capacity of a downstream bottleneck on the freeway. Because long traffic queues are likely to exist with restrictive control, traffic is “encouraged” to divert to alternate facilities or modes.

Non-Restrictive Control. Non-restrictive control refers to a mode of operation of the ramp control signal where ramp demand is allowed to enter the freeway as quickly as possible. With non-restrictive control, demand metering rates are set to the maximum, thus allowing as much demand on the ramp to be serviced as quickly as possible. The primary objective of

[1] Care should be taken to ensure that adequate acceleration length, sight distances, and ramp storage lengths exist if a ramp meter is to be installed as part of a transportation management plan for a freeway construction/maintenance zone.

non-restrictive control is to “smooth” the arrival rate of vehicles entering the freeway by breaking up large platoons on the ramp.

Most TxDOT ramp control signals operate in a non-restrictive mode.

Freeway-to-Freeway Metering

While it is not common practice for TxDOT to meter freeway-to-freeway connectors, this practice is not expressly prohibited by TMUTCD and is a strategy deployed in many locations in the United States. The following guidelines for selecting appropriate locations for implementing freeway-to-freeway metering have been adapted from the *Ramp Management and Control Handbook* (*1*):

- Meters on any freeway-to-freeway ramp should be installed only after an engineering analysis shows that the mainline flow of the through (or unmetered) freeway is improved so that freeway-to-freeway ramp users are rewarded.

- Freeway-to-freeway ramp metering may be appropriate where more than one ramp merges together before feeding the mainline and where congestion on the ramp occurs with regular frequency (four or more times a week during the peak periods).

- Freeway-to-freeway ramp metering should only be considered where recurrent congestion occurs and/or where diversion to alternate routes is being encouraged. Route diversion should only be encouraged where suitable alternative routes exist.

- Freeway-to-freeway ramp metering should be employed judiciously. Avoid multiple meters within a relatively short distance.

- Freeway-to-freeway metering should be used in only a merge situation. Avoid metering on single-lane, freeway-to-freeway connectors that result in adding a new travel lane on the through freeway.

- Use a metering rate that minimizes the likelihood of queues from the ramp impeding traffic flow on the upstream freeway. When queues for the meter begin to impede traffic flow on the upstream freeway, either increase the metering rate to reduce queue growth or provide additional storage capacity on the ramp.

- Freeway-to-freeway metering should only be used on ramps that are level or have a slight downgrade. This will allow heavy vehicles to accelerate easier from the meter. Avoid installing ramp meters where the sight distance for drivers approaching the meter is not adequate to allow them to see the queue in time to safely stop.

- Surveillance and monitoring should be provided at all freeway-to-freeway connectors that are metered. Communications to the ramp meter should also be provided so that operators can change operating parameters if needed.

References

1. L. Jacobson, J. Stribiak, L. Nelson, and D. Sallman. *Ramp Management and Control Handbook*. Report No. FHWA-HOP-06-001. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., January 2006. Available at http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/pdf/rm_handbook.pdf. Accessed August 8, 2008.

Section 5

Basic Operations

Introduction

The following provides some basic guidelines for operating ramp control signals.

Hours of Operations

- Ramp control signals should only be operated when recurring congestion occurs on the freeway or when periodic or sporadic congestion forms as a result of traffic generated from special events.

- When ramp control signals are first implemented in a region or new corridor, they should be operated only during peak commute hours to allow staff to gain experience in operating the signals, to make their operation predictable, and to reduce motorist confusion or frustration. Operating the ramp control signals at predictable times allows the public to know with relative certainty when the ramp meters will be on and off.

- For most TxDOT ramp control signals, the general hours of operations are as follows:

    - AM Peak Period: 6:00 – 9:00 AM

    - PM Peak Period: 3:00 – 7:00 PM

- It may be necessary to adjust the general start earlier and extend the end time later during the peak periods based on traffic demand. This is especially true for high volume ramps located in suburban areas. Activation of the ramp control signal should be considered when the traffic volume in the rightmost lane of the freeway reaches approximately 1600 vehicles per hour per lane.

- Whenever possible, ramp meters should be operated in a traffic responsive mode so that the actual start time of metering operations is dependent upon traffic volume needs in the freeway.

- Operating ramp control signals in off hours is not recommended for relatively new systems because residents may not be familiar with their operation.

- As the system matures and drivers become more familiar with their operation, the hours of operation may be expanded to include more of the peak period and/or off-peak conditions. Traffic sensors may be used to automatically activate and deactivate the ramp meter during off-peak period hours when traffic congestion occurs because of collisions or other incidents.

Establishing Base Metering Rate

The base metering rate is the flow rate of traffic through the ramp meter signal. This flow rate is determined by the cycle length of the meter as well as the operating strategy for the ramp control signal. Table 5-1 shows the recommended operating strategy for different ramp demand levels.

Table 5-1. Appropriate Number of Metered Lanes and Release Rate Based on Ramp Volume.

Ramp Volume	Recommended Number of Lanes under Ramp Control Signal	Release Rate of Vehicles from Ramp Control Signal (vehicle per green)
<1000 vph	Single	Single
900 – 1200 vph	Single	Multiple
1200 – 1600 vph	Dual	Single
1600 – 1800 vph	Dual	Multiple

Source: Reference (*1*).

Single-Lane, Single-Entry Ramps. The following parameters are used to establish the base metering rates for single lane ramps where only one vehicle per cycle is allowed through the ramp control signal.

- *Minimum green time* – This is the amount of time that the green indication will be displayed to vehicles. For single-lane, single-entry ramp control signals, the duration of the green time is recommended to be 1 second.
- *Yellow time* – In Texas, it is common practice to follow a green indication with a yellow indication for ramp control signals. For ramp control signals, the duration of the yellow interval is recommended to be 1 second.
- *Red time* – Red times are set to achieve the desired flow rate.

Table 5-2 shows the red times and cycle lengths required to achieve a desired flow rate through the ramp control signal. Table 5-3 shows the resulting flow rate that will be achieved through the ramp control signal as a result of implementing select red time intervals. In no case should the red time be set to less than 1.8 seconds.

The desirable minimum cycle length to be used with single-lane, single-entry metering is 4.5 seconds. This results in a meter capacity of 800 vph (per lane) (*2*). The minimum cycle length to be used with single-lane, single-entry metering is 4.0 seconds. This results in the meter capacity of 900 vph (per lane) as shown in Table 5-1.

Table 5-2. Red Times and Total Cycle Length to Achieve Desired Meter Capacity for Single-Lane, Single Entry Ramp Control Signals.

Desired Meter Capacity (vph)	Red Time (seconds)	Total Cycle Length (seconds)*
900	2.0	4.0
850	2.2	4.2
800	2.5	4.5
750	2.8	4.8
700	3.1	5.1
650	3.5	5.5
600	4.0	6.0
550	4.5	6.5
500	5.2	7.2
450	6.0	8.0
400	7.0	9.0
350	8.3	10.3
300	10.0	12.0

* Green Time = 1 second; Yellow Time = 1 second.

Table 5-3. Resulting Meter Capacity for Different Implemented Red Times for Single-Lane, Single Entry Ramp Control Signals.

Implemented Red Time (seconds)	Total Cycle Length (seconds)*	Resulting Meter Capacity (vph)
1.8	3.8	947
2.0	4.0	900
2.5	4.5	800
3.0	5.0	720
3.5	5.5	655
4.0	6.0	600
4.5	6.5	554
5.0	7.0	515
5.5	7.5	480
6.0	8.0	450

* Green Time = 1 second; Yellow Time = 1 second.

Single Lane, Multiple Cars per Green. When there is a need to service higher ramp demand than can be accommodated in a single-lane, single-vehicle metering rate, there may be a need to perform "platoon" or "bulk" metering. With platoon or bulk metering, two or more vehicles are permitted to enter the freeway during each green indication. Table 5-4 shows the recommended timing parameters that may be used in implementing platoon metering initially, unless a local study is performed at the ramp.

Table 5-4. Recommended Controller Timing for Platoon Metering.

Interval	Vehicles per Cycle					
	1	2	3	4	5	6
Red	2.00	2.00	2.32	2.61	2.86	3.08
Yellow	1.00	1.70	2.00	2.22	2.41	2.58
Green	1.00	3.37	5.47	7.35	9.13	10.83
Cycle Length	4.0	7.08	9.78	12.19	14.40	16.49
Meter Capacity	900	1017	1104	1181	1250	1310

Source: Reference (2).

Dual-Lane Metering. Dual-lane metering is a type of ramp operation in which traffic is split into two lanes on the ramp and each lane is controlled by a ramp control signal. In this type of operation, the controller operates by alternating the green-yellow-red cycle for each metered lane. In most deployments in Texas, a synchronized cycle is used so that the green indications never occur simultaneously in both lanes. Furthermore, the green indications are timed to allow a constant headway between vehicles from both lanes. Dual-lane metering can provide a metering capacity of 1600 to 1700 vph, approaching the geometric-related capacity of the ramp. Dual-lane ramps also provide more storage for queue vehicles (*2*).

Only TxDOT's new ramp signal controller, the Eagle RMC 300 controller with a software version dated February 1998 or later, is capable of running dual-lane metering. Older versions of the controller (version 1.01, dated July 1992) can meter only one lane.

Setting Initial Traffic Responsive Detector Parameters

In traffic responsive mode, traffic sensors upstream of the entrance ramp can be used to trigger different metering rates at the ramp control signal. Table 5-5 shows the suggested initial freeway occupancy levels that can be used to trigger different ramp control signal metering rates for different freeway operating speeds. This table assumes a 6-foot detection zone and an average vehicle length of 18 feet. These occupancy thresholds should be fine-tuned in the field after the ramp control signal has been installed and is operating.

Table 5-5. Initial Loop Occupancy Thresholds for Triggering Different Traffic Responsive Metering Rates.

Metering Rate (vph)	Maximum Freeway Service Volume (vphpl)	Freeway Free-Flow Speed			
		55 mph*	60 mph	65 mph	70 mph
900	1500	12.4	11.4	10.5	9.8
800	1600	13.2	12.1	11.2	10.5
700	1700	14.1	12.9	12.0	11.2
600	1800	14.9	13.7	12.8	12.1
500	1900	15.8	14.6	13.7	13.0
400	2000	16.8	15.7	14.8	14.0
300	2100	18.0	17.0	16.0	15.2

* Actual settings may vary depending upon local conditions.

Setting Queue Management Parameters

With most TxDOT installations, the ramp controller uses an excessive queue detector installed 400-600 feet upstream of the meter stopbar to prevent excessive queues from blocking traffic movements at the upstream signalized intersection or free U-turn lane. When a queue is detected, the controller overrides normal metering operation by shutting the metering operation. It resumes metering when the queue condition ceases to exist. To determine these queue states, the controller utilizes two user-configurable parameters, namely; Detector Occupied Trigger and Detector Un-occupied Trigger.

A Detector-Occupied-Trigger setting equal to *x* seconds results in a queue condition of "True" if the detector is continuously occupied (100% occupancy) for *x* seconds. A small value of this parameter implies snappy operation and a large value implies sluggish operation. Depending on the difference between the hourly meter demand (*D*) and the effective metering rate (*M*) in vehicles per hour (VPH), the programmed value may range from 6 to 10 seconds. An example value of 8 seconds could be used as the initial value for a ramp with 400-feet storage. It is an iterative process that could be adjusted up or down based on individual ramp conditions.

A Detector-Unoccupied-Trigger setting of *y* seconds results in a queue condition equal to "False" if the detector is continuously un-occupied for *y* seconds. A very small value of this parameter will result in the resumption of metering operation before a queue has cleared, while a large value of this parameter will continue flush operation even after the queue has cleared. Because a steady green of 15 seconds (an additional flush period) precedes the resumption of normal metering after each flush, the range of this parameter should be between 2 to 4 seconds. An example value of 3 seconds is suggested during initial setup and could be adjusted up or down based on individual ramp conditions.

Start-up and Shutdown Procedures

To reduce the potential for rear-end collisions, the following procedure is recommended for starting up the ramp meter. This start-up procedure applies for both normal start-up as well as starting up after a flushing operation:

1. Activate the flashing beacon on the advance warning sign to warn motorists that the ramp meter is about to begin operating.

2. Delay activating the ramp control signal or display a solid green for a time equivalent to the travel time of free-flowing entering ramp traffic from the advance warning sign to the stop line of the ramp control signal. This travel time should be observed locally in the field during the ramp control signal installation process.

3. At the same time, display a solid green indication on the ramp meter control signal for a minimum of 5 seconds. A solid green indication is recommended because it provides positive guidance that the ramp control signal is about to cycle. Five seconds is recommended because this is traditionally the minimum green time used at intersection traffic signals.

4. Display a solid yellow ball for at least 1 second to allow drivers to notice that the ramp control signal is beginning to terminate the green indication. A 3-second solid yellow ball, as it is the minimum yellow clearance interval typically recommended at intersection traffic signals, could be used if violations become a problem at start-up.

5. The ramp control signal should "rest" in a red indication and only begin cycling if demand is present on the demand detector. Once traffic demand is detected on the demand detector, the ramp control signal can begin normal operations.

To terminate operations of the ramp control signal, the following process should be used:

1. The shut-down sequence should begin when the ramp control signal is resting in a solid red indication for a minimum of the travel time

2. The ramp control signal could then transition to normal solid green indication and should remain there for a minimum of 5 seconds or the time it takes to clear the vehicles from the storage distance.

3. Following a solid green interval, the ramp control signal may go to a dark (or no) signal display.

References

1. L. Jacobson, J. Stribiak, L. Nelson, and D. Sallman. *Ramp Management and Control Handbook*. Report No. FHWA-HOP-06-001. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., January 2006. Available at http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/pdf/rm_handbook.pdf. Accessed August 8, 2008.

2. N.A. Chaudhary, Z. Tian, C.J. Messer, and C.L. Chu. *Ramp Metering Algorithms and Approaches for Texas.* Report No. FHWA/TX-05/0-4629-1. Texas Transportation Institute, Texas A&M University System, College Station, TX. September 2004.

Section 6

Removal

Introduction

Changing traffic patterns over time may eliminate the need for a ramp control signal. Often, reconstruction of the freeway increases capacity and improves traffic operations so that ramp control signals are no longer necessary.

Removal Criteria

Neither the TMUTCD nor the national MUTCD provide specific criteria that can be used to determine if and when to remove the ramp control signal. As in the case of an intersection traffic signal, engineering judgment should be used. Removal of a ramp control signal should be considered when one or more of the following situations exist:

- The freeway is reconstructed so that the ramp is the beginning of a new freeway lane.
- Traffic demand on the ramp no longer exceeds the minimum volume threshold for installing a ramp meter (300 vph).
- The rate of crashes in the merge area exceeds the mean crash rate of other ramps that use ramp control signals.
- A substantial increase in rear-end crash rates is observed for vehicles on the frontage road.
- The meter availability during the peak operating hours is much less than 70 percent.
- The prevailing speed of the freeway exceeds 50 mph throughout the entire day (result of reconstruction of the freeway).
- The annual cost of operating and maintaining a ramp control signal exceeds the estimated benefits.
- Delays to the ramp traffic exceed the threshold established by the district engineer, if other operational changes cannot correct it.[1]
- Driver noncompliance reaches an unacceptable level and increased enforcement activities have failed to correct noncompliance issues.

Appendix B contains a Ramp Control Signal Removal Authorization Form.

[1] The Houston District's policy is delays cannot exceed 2 minutes unless special permission is given by the District Engineer. In Minneapolis, this threshold is set to 4 minutes.

Process for Removing Ramp Control Signals

- An information sign should be installed indicating that the ramp meter is to be removed. It is recommended that the sign be in place at least 2 weeks prior and 2 weeks after removal of the ramp meter. This sign should replace the "RAMP METERED WHEN FLASHING" sign. An additional sign may be placed near the ramp control signal heads. An alternative would be to use a portable DMS indicating the date the meter is to be removed.

- Ramp control signal heads should either be bagged or pointed away from the entering ramp traffic for the 2-week period after the meters have been deactivated.

- If, after a period of non-operation, ramp merge area operation and safety is acceptable, the signal heads, signs, and ramp control signal controller can be removed from the field.

- If the ramp control signal is to be removed as part of a reconstruction project, it is recommended that the in-ground infrastructure (conduit and pull-boxes for cable runs and controller cabinet, and traffic sensors for the freeway) be reinstalled as part of the construction activities. It is not recommend to reinstall loop detectors or other traffic sensors for the ramp installed as part of the reconstruction, as exposure to the weather and traffic may cause these sensors to fail before a ramp control signal is needed.

Section 7

Special Operations

Introduction

In certain circumstances, it may be necessary to provide special operations at some ramp control signals. The following outlines two situations where special operations may be required at ramp control signals.

HOV Ramp Control Bypass Lanes

High occupancy vehicle (HOV) bypass lanes are a technique for providing HOVs (i.e., public transit vehicles, carpools, vanpools, etc.) preferential treatment at ramp control signals. With HOV bypass lanes, HOVs are allowed to bypass the ramp control signal and enter the freeway without having to stop at the ramp control signal.

Each district engineer is responsible for establishing a policy on the use of HOV ramp control signal bypass lanes in their respective district. The decision to install and operate HOV ramp control bypass lanes should be the result of an engineering investigation.

Criteria for Installing HOV Bypass Lanes. The following criteria, adapted from the California Department of Transportation (CalTrans), should be used in assessing the need for an HOV ramp bypass lane (*1*):

Control: An analysis of HOV traffic volumes shall be made to determine the impact on mainline traffic flows. Where adverse impacts exist, consideration should include metering the HOV preferential lane and/or more restrictive metering of the SOV lane(s). Consideration should be given to metering the HOV preferential lane if platoons from local signalized intersections adversely affect the operation of the freeway. Storage capacity and effects to local arterials should also be addressed.

Merge Conditions: Prior to entering the freeway, all vehicles on the on-ramp should be provided with adequate space to safely merge with each other. The safest merge condition is when the speeds of the merging vehicles are identical. When the speed differentials between HOVs and [single-occupancy vehicles] SOVs are excessive, consideration should be given to metering the HOV lane.

Enforcement: The ability to safely enforce occupancy violations of HOV lanes is essential. [Local law enforcement agencies] should be consulted for their recommendation of enforcement operations at each HOV preferential lane location.

Corridor Operations: In corridors where ramp meters are already operational, the existing metering method may be used as a criterion for additional installations in the same corridor. Should alternate metering methods be proposed along a corridor, local agencies should be consulted.

The criteria listed above can be applied to new and existing ramp meter installations. If it is being applied to an existing ramp meter, the following criteria should also be used:

> *Accident History: The accident history of the ramp needs to be investigated. If either the ramp or any portion of the freeway within 500 feet of the ramp gore has been flagged as a high accident concentration location, each accident report should be reviewed in detail to determine whether or not the HOV operation during the metered period was a contributing factor. If evidence suggests that it could have been a contributing factor to the accident, consideration should be given to metering the HOV preferential lane.*

If the district engineer decides that installation of an HOV ramp control signal bypass is justified, district personnel should consult with the Traffic Operations Division for assistance in establishing ramp control signal parameters.

Design Guidelines for Installing HOV Bypass Lanes. The following guidelines, adopted from the Arizona Department of Transportation, are provided regarding the installation of HOV bypass lanes (*2*):

1. *HOV preferential ramp meter lanes should be considered only in locations with mainline HOV lanes or transit facilities.*
2. *HOV preferential ramp meter lanes should be considered for locations that have concurrence from local law enforcement agencies to provide adequate enforcement.*
3. *The HOV preferential lane should be located on the right side, if present.*
4. *Specific HOV lane treatments must be tailored to the unique conditions at each ramp location.*
5. *HOV preferential lanes should not be installed when pavement delineation and signing cannot provide adequate guidance to direct SOVs to safely enter or merge into the SOV lane.*
6. *HOV lanes should not be installed when roadway geometrics could cause an SOV to become inadvertently trapped in the HOV lanes. A common example would be dual left turns entering a freeway ramp.*
7. *HOV lanes should not be installed when the storage area of both lanes is needed for general-purpose ramp queue storage.*
8. *HOV lanes should not be installed when a direct access HOV drop ramp is available within 1.25 miles of the proposed HOV lane. An HOV drop ramp is a dedicated ramp serving a freeway HOV lane, without the need to merge across multiple general-purpose lanes to enter the freeway HOV lanes.*

9. *When HOV lanes are initially implemented, they should be implemented with the understanding that the HOV lane may be used as a second metered lane in the future.*

Incident Conditions

Incidents (such as stalled vehicles or crashes) are temporary bottlenecks located downstream of one or more ramps. Because they are temporary in nature, managing traffic during incident conditions may require special operations of the ramp control signal.

Ramp Control Signal Upstream of Incident. Freeway ramp control signals are an effective traffic management tool that can be used to lessen the impact of incidents during freeway operations. During incident conditions, the ramp control signals upstream of the incident location can be used to limit the amount of traffic demand from entering the freeway. This can be done automatically (if the ramp control signal is operating in a traffic responsive mode) or manually. If the ramp meter is to be operated in a traffic responsive mode, the freeway occupancy threshold needs to be set in the controller to correspond to the desired metering rate. Note that the controller will not likely be able to distinguish between recurring congestion and incident congestion – only that congestion is present – so the same thresholds used to transition between ramp meter plans will likely to be used to set new metering rates during incident conditions.

If operators in the control center are able to communicate with the ramp control signal in the field, new metering rates can be manually activated during incident conditions. To do this, however, operators in the control center need to (1) be able to communicate with the ramp signal controller, and (2) have the ability to monitor traffic operation through video surveillance. Unless these conditions are present, manual operation of the ramp control signals is not recommended.

Ramp Closures during Incident Conditions. A ramp control signal should never be used to close a ramp during an incident condition by displaying a solid red indication. If during an incident it is desired to close a ramp that is metered, the ramp should be physically closed by law enforcement personnel. Only after law enforcement personnel are physically blocking the ramp should the ramp control signals (and any active advance warning devices) be deactivated and a dark signal indication displayed on the signal heads. Until law enforcement personnel are blocking the ramp, the ramp control signal should be allowed to cycle, even if it queues become extensive. It may be desirable, however, to operate the signals with a very low metering rate to limit the amount of traffic entering the freeway.

References

1. *Ramp Meter Design Manual.* Prepared by the Traffic Operation Program, California Department of Transportation. January 2000.
2. R*amp Meter Design, Operation, and Maintenance Guidelines.* Arizona Department of Transportation. April 2003.

Section 8

Measuring and Monitoring Performance

Introduction

An evaluation of the impacts and effectiveness of a ramp control signal should be performed with every installation. Evaluations can have one or more of the following forms:

- Pre-deployment studies – where the potential effects of implementing a ramp control signal are estimated prior to the installation of the signal. This type of study is usually done to assist in the decision-making process as to whether or not to install the system.
- System impact studies – where the actual effects of implementing a ramp control signal are measured. Generally, the observed effects after the installation are compared with the same effects before installation of the signal.
- Benefit/cost analyses – where the estimated or measured benefits of installing the ramp control signal are compared with the costs associated with the construction and installation of the signal. These types of analysis are performed to evaluate the cost effectiveness of the installation.
- Ongoing system monitoring and analysis – where continuous, real-time performance data are analyzed for the purpose of providing feedback to system operations.

The type of evaluation that is performed depends on where the ramp control signal is in its life cycle.

Performance Measures

Performance measures represent the traffic and travel characteristics that are measured to assign benefits of installing a system to the traveling public. Performance measures should reflect the goals and objectives for installing the ramp control signal, be readily measurable, assist in the decision-making process, and facilitate improvement.

Freeway Performance. The following measures are recommended for evaluating the effectiveness of ramp control signals on freeway performance:

- frequency and rate of crashes (collisions) occurring on the freeway in the vicinity of the ramp,
- observed travel times and speeds of traffic traveling on the freeway,
- amount of average delay experienced by freeway travelers (delay could be estimated by taking the difference in observed travel times and the free-flow travel times),

- variability in travel times or speeds on the freeway,
- observed throughput (or volume) of vehicles utilizing the freeway section,
- level of service or volume-to-capacity ratio on the freeway section,
- estimated amount of fuel consumption used by vehicles traveling on the section of freeway, and
- amount of vehicle emissions produced by vehicles traveling on the section of freeway.

National Cooperative Highway Research Program (NCHRP) Web-Only Document 97 (*1*) contains a comprehensive list of performance measures that agencies have used to monitor and assess freeway performance. Appendix C lists some of the measures that might be appropriate in analysis of ramp control signals.

Ramp Performance. The following measures are recommended for evaluating the effectiveness of ramp control signals on ramp performance:

- frequency and rate of crashes (or collisions) on the ramp and surface street attributed to the ramp control signal,
- amount and standard deviation of delay (seconds) experienced by ramp traveling waiting to enter the freeway,
- travel time associated with drivers entering the ramp,
- throughput (or volume) of traffic utilizing the ramp,
- percent of time ramp queues spill back and impact adjacent arterial street performance,
- amount of vehicle emissions produced by traffic waiting to enter the freeway from the ramp, and
- estimated amount of fuel consumed by vehicles waiting to enter the freeway from the ramp.

Merge/Weave Area Performance. The following measures have been suggested for gauging the effects of ramp control signals on freeway-ramp merge area performance (*2*):

- number of crashes (or collisions) observed in the merge area,
- number of conflicts or erratic maneuvers that occur in the merge area,
- throughput (or the number of vehicles passing through the merge area), and
- speed of traffic in the merge area.

Assessment Approaches

"Before and After" Analyses. A "before and after" study is a common approach used to measure the effectiveness of ramp meters. With a before and after study, operational data are collected before the ramp control signal is installed. The same data are then collected after the ramp control signal has been activated. Before and after studies provide an accurate assessment of the *actual* benefits as opposed to *estimated* or *predicted* benefits of installing a ramp control signal.

Modeling. Modeling is an analytical approach to *estimating* or *predicting* the benefits to be derived from installing a ramp control signal. Modeling is often used to assess operations and impacts before a ramp control signal (or system of signals) is installed. Modeling can also be used to provide an assessment of different control strategies to a range of travel conditions. It is particularly well-suited for estimating the system-wide impact of implementing ramp control signals. The following lists the different types of model strategies that can be used to assess the impacts of ramp control signals (*3*):

- *Sketch-Planning Tools* – these models are intended to provide an "order-of-magnitude" estimate of the impacts of different control strategies on travel demand and operations. Sketch-planning tools are usually used at the alternatives analysis stage of a project.

- *Travel Demand Models* – these models are generally used to obtain a system-wide perspective of or to model the effects of driver decisions on traffic operations. These models are intended to model driver route and mode choice decisions to predict how travel demand will change in the presence of different operational controls. Within these models, traffic is allowed to dynamically alter route and/or mode choice decisions in response to predicted traffic conditions. Travel demand models do not provide detailed, site specific analysis of traffic operations within the merge area or along a segment of the freeway.

- *Analytical/Deterministic Tools* – these models generally implement the procedures found in the *Highway Capacity Manual* to quickly estimate the effects of ramp control signals on capacity, traffic density, operating speed, queuing, etc. This analysis technique is best suited for analyzing the performance at isolated freeways or segments of freeways.

- *Simulation* – these models use mathematical processes and complex traffic flow theories to estimate the movement of individual vehicles. Simulation is ideal for analyzing the effects of different control strategies on isolated or small-scale systems where it is important to capture the interactions between vehicles. Simulation is also ideal for analyzing how traffic operates within the freeway ramp merge area.

Monitoring Effectiveness

Monitoring the operation is different than measuring performance in that monitoring is a continuous process (as opposed to the measuring, which implies a sampling of performance conditions). Monitoring allows district operations personnel to identify the manner in which the operation of the ramp meter signal can be modified to maximize its effectiveness.

Monitoring implies the deployment of technology and equipment in the cabinet that allows the operation of the ramp control signal (as opposed to its impact on traffic operations) to be measured.

The following lists some of the measures that can be used to monitor the operations of the ramp control signal:

- *Average Ramp Meter Start Time* – average time-of-day at which ramp control signal is first activated.
- *Average Ramp Meter End Time* – average time-of-day at which the ramp control signal is deactivated for the last time.
- *Average Number of Activations* – average number of times that the ramp control signal is cycled to service vehicles on the ramp
- *Average Activation Duration (minutes)* – average number of minutes during a typical day that the ramp meter was in operation. It can be computed by averaging the daily difference in the ramp meter end time and the ramp meter start time for the operation period.
- *Average Cycle Time (seconds)* – average cycle length for the ramp control signal. The cycle length can be measured from the beginning of a red indication to the beginning of the next red indication.
- *Average Number of Vehicles Serviced during a Cycle* – average number of vehicles that traverses the stop line of the ramp control signal (or passage detector, if available) during each cycle of the ramp control signal.
- *Average Wait Time* – average amount of time that a driver has to wait in the queue before being serviced by the ramp control signal. Wait time is defined as the time difference between when the vehicle first arrived at the back of the queue to when it crosses the stop line (or passage detector) at the ramp control signal.
- *Average Ramp Control Service Flow Rate (vph)* – this is computed by dividing the average number of vehicles serviced during a cycle by the average cycle length. This value is then multiplied by 3600 to convert to hourly flow rate.
- *Average Total Service Flow Rate (vph)* – average of the total number of vehicles serviced on the ramp during the hours of operation. Note that this measure also includes the number of vehicles that used the ramp during flushing operations and during the ramp control signal start-up time (if any) after each flush.
- *Average Freeway Speed (mph)* – average speed of freeway traffic during the time period at which the ramp control signal is operating. This measure can be obtained from the freeway traffic sensor data.

- *Ramp Signal Control Efficiency* – ratio of the average ramp control service flow rate to the average total service flow rate. If this value approaches unity, then the majority of traffic serviced at the ramp is under the control of the ramp signal. As this value approaches zero, it implies most of the ramp demand is serviced while the ramp meter is inactive.

If flushing is permitted at the ramp control signal, the following performance measures may also provide insight into effectiveness of the ramp control signal:

- *Average Number of Ramp Meter Flushes* – average of the number of times during the operation period that the ramp meter was operating in the flush mode. A flush is characterized by a deactivation of the signal indication (i.e., the signal heads are "dark" or not illuminated) during established hours of operations for the ramp.

- *Flush Frequency (per 10 min)* – measure of the average number of times that the ramp control signal was operating in the flush mode over a 10-minute interval. It can be computed by dividing the total number of flushes by the total number of 10-minute intervals that exist when the ramp meter is in operation. For example, if the ramp meter was in operation for 1 hour (60 minutes) and flushed each interval, the total number of 10-minute intervals of operation is 6.

- *Average Time-to-First Flush (sec)* – this is the average of the difference in time, in seconds, from the ramp meter start time to the time of day the first flushing operation occurred. This measure provides an indication of how quickly ramp demand exceeds the capacity of the ramp meter.

- *Mean Flush Duration (sec)* – average (or mean) time, in seconds, that the ramp control signal was operating in the flush mode. It is computed by averaging the difference in time from when the meter began operating in the flush mode to when the meter ended flush operation.

- *Median Flush Duration (sec)* – 50^{th} percentile time, in seconds, that the ramp control signal was operating in the flush mode.

- *Average Maximum Flush Duration (sec)* – average time, in seconds, of the largest time duration that the ramp meter was operating in the flush mode.

- *Mean Time-to-Next Flush (sec)* – average time, in seconds, that elapses between successive flushing events. This time is measured from the start of one flush event to the start of the next flush event.

- *Median Time-to-Next Flush (sec)* – 50^{th} percentile time, in seconds, which elapses between successive flushing events.

- *Ramp Signal Control Availability* – ratio of the average total amount of time that ramp control signal was operating over the average activation duration (i.e., the average total duration of the operation). The total amount of time the ramp control signal was operating can be computed by subtracting the total of the time that the ramp control signal was operating in the flush plus start-up mode (if any) from the total operating duration. The ramp signal control effectiveness is a measure of the availability of the amount of time that the ramp control signal is used to service ramp traffic demand.

References

1. *Guide to Effective Freeway Performance Measurement: Final Report and Guidebook.* NCHRP Web-Only Document 97. Submitted August 2006. Available at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w97.pdf

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Section 9

Enforcement

Introduction

Continuous and selective enforcement is critical to achieving high compliance with ramp signal indications. Without adequate and consistent enforcement, driver disrespect for ramp control signals can limit their effectiveness as a tool for maintaining traffic flow on the freeway. Districts installing ramp control signals need to develop, in conjunction with local law enforcement personnel, a program for providing enforcement at ramp controls.

Enforcement Strategies

The following enforcement strategies are recommended as part of a new ramp control signal installation:

- Active enforcement should be planned during the first month of initial operations for a new ramp control signal.
- After an initial month, spot enforcement should be planned on a routine basis.
- Traffic management center (TMC) personnel should report to enforcement agencies any location(s) that experience high violation rates.
- Where deemed necessary, enforcement areas where officers have a safe point to observe and pull over violators may be provided. These enforcement areas should be situated so that they have a minimal effect on traffic operations when enforcement activities are being performed.

A public awareness campaign regarding the purpose and intent of a new ramp control system program is encouraged for locations that are installing their first ramp control signals. The purpose of the public awareness campaign is to inform motorists of the anticipated benefits of the ramp control signal and to highlight the desired driving behavior. To encourage voluntary compliance, the public awareness program should also highlight the consequences of violating ramp control signal indications.

Enforcement Zones

It is recommended that each new ramp meter design incorporate an area where enforcement activities can be performed. The enforcement areas can be placed on entrance ramps downstream of the stop bar. Lights or indications that can be observed from the enforcement area may be placed on the back of the ramp control signal to aid in the enforcement activities. Figure 10-1 shows an example of a potential location for a law enforcement zone. These should be large enough to contain a minimum of two vehicles. Enforcement zones should also be paved to facilitate their use.

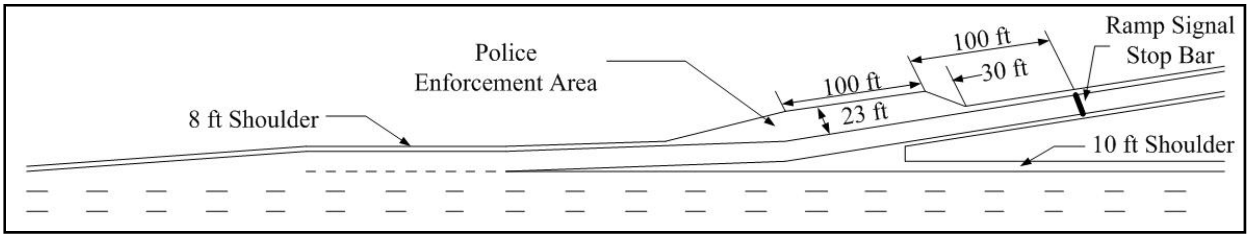

Figure 10-1. Example of Police Enforcement Zone.

The following are guidelines for the design of ramp enforcement areas (*1,2*). The design of enforcement areas should be reviewed by local law enforcement during the site design process.

- Enforcement areas are not required for single-lane meters; however, provision for future enforcement areas should be considered for all new ramp control signal installations, if geometric constraints allow.
- Paved enforcement areas should be provided when possible.
- An enforcement area should be considered on ramps having HOV preferential treatments.
- The enforcement area should begin as close to the ramp control signal stop bar as practical, without creating a geometric situation that would allow vehicles to queue up in the enforcement area.
- Enforcement areas should be a minimum of 15 feet wide; 23 feet is desirable.
- Enforcement areas should begin with a 30-foot long taper, when possible.
- Enforcement areas should be 75 to 100 feet long.
- Enforcement areas should taper back into the shoulder with a taper in the range of 10:1 to 15:1 to allow enforcement vehicles to safely merge into traffic.
- Enforcement area dimensions may be customized to fit site conditions.

References

1. *Ramp Meter Design Manual.* Prepared by the Traffic Operation Program, California Department of Transportation. January 2000.
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Section 10

Maintenance

Introduction

Providing adequate maintenance is critical to ensuring the long-term success and acceptance of ramp control signal systems. By having a maintenance plan for ramp control signals (and other traffic control devices), agencies maximize returns on their investments and help ensure that the technologies and equipment operate up to and possibly beyond their design life. Failure to maintain ramp control signals to an acceptable standard can result in disruptions of equipment and strategies. Common maintenance activities include the following:

- replacing defective or broken components,
- updating software and system inventories,
- logging events,
- testing equipment, and
- cleaning system components.

Two types of maintenance activities need to be included in a maintenance program for ramp control signals: responsive maintenance and preventative maintenance.

Responsive Maintenance

Responsive maintenance is the type of maintenance that occurs in response to alarms, customer requests, or identified problems. Usually, it involves repairing or replacing a failed piece of equipment to return the ramp control signals (or one or more of its components) to full operation or functionality (or as intended by the manufacturer). Generally, responsive maintenance is an emergency or critical repair – actions need to be taken based on the priority of the subsystem that has failed. Responsive maintenance takes precedence over preventative maintenance because of its emergency-like nature.

Preventative Maintenance

Preventative maintenance involves performing checks, tests, inspections, record-keeping, cleaning, and replacement based on the function and rated service life of the equipment. The emphasis on preventative maintenance is on checking for proper operation and taking proactive steps to repair or replace defective equipment, thus ensuring that problems are not left until equipment fails.

The following activities should be performed at least every 6 months on each ramp control signal installation:

- Inspect all ramp control signals/flashing beacon signs and clean or replace as necessary.
- Inspect all signal lenses and clean or replace as necessary.
- Inspect each signal head for damage and replace as necessary.
- Refocus all signal heads and align with the correct lane of traffic.
- Replace all signal lamps in each signal head (unless light-emitting diodes [LED] signals are used).
- Inspect each loop detector amplifier and retune or replace as necessary
- Inspect each time clock (internal or external) and reset as necessary.
- Inspect all steel pole surfaces for scratches or rust and apply cold galvanizing material as necessary.
- Inspect each foundation bolt for tightness and retighten as necessary.
- Inspect all pull-boxes and replace as necessary.
- Inspect pole bases and controller cabinets for insect and rodent buildup, remove any buildup or debris, and replace pesticides as necessary.
- Check ventilation fans and thermostats. Install new dust filters.
- Lubricate locks, ventilation fan motors, and graphite the cabinet locks.
- Check voltages and current for abnormal readings.
- Check cabinet seals and repair or recaulk, if necessary.
- Remove graffiti from cabinet.
- Check communication system to traffic management center, if provided.
- Log service activities performed.

In addition to these maintenance items, routine field inspections should also be performed at each ramp meter location. As part of these inspections, the following items should be checked:

- Review the placement and condition of all advance warning and regulatory signs. Observe if the signs are in good condition, missing, damaged, turned, or obstructed. Check to see if vegetation is impeding visibility to these signs.

- Review the condition of the pavement markings associated with the ramp control signals. This includes the stop bar, edge lines, lane skips (if any), and HOV lane designation symbols (if any). Note if pavement markings are missing or faded.

- Observe the general condition of the pavement on the ramp. Note if the pavement conditions are new, good, fair, or poor. Note if pavement appears to be "polished" or if potholes are present. If loop detectors have been installed, review the pavement conditions of the saw cuts and note if depressions, cracks, or deterioration is occurring. Check that saw cut seals are still intact.

The appropriate maintenance section or area office should be notified of any deficiencies observed during the inspection.

Appendix A

Ramp Control Signal Authorization Form

Instruction for

Ramp Control Signal Authorization Form

The Ramp Control Signal Authorization form is intended to provide TxDOT operations personnel with criteria for determining if installing a ramp control signal may benefit main lane freeway traffic speed by controlling the arrival rate and breaking up platoons of traffic entering from the ramp. These criteria were developed based upon available literature as well as research performed for TxDOT. These criteria are only guidelines – the ultimate decision to install a ramp control signal shall be based upon engineering judgment.

The Ramp Signal Authorization form is divided into three primary sections: traffic flow considerations, safety considerations, and other considerations. At a minimum, Criteria 2 through 5 in the Traffic Flow Considerations should be satisfied before justifying the installation of a ramp control signal. The criteria provided in the Safety Considerations and Other Considerations may be used to provide further guidance to decision-makers on whether or not to install a ramp control signal.

Ramp Control Signal Authorization Form

Freeway Name: ______________________________ **Direction of Travel**: __________

Ramp Name: ______________________________

Freeway Control Section: ____________________ **Freeway Reference Marker**:____________________

City Name: ____________________ **County Name:** ____________________ **District:** ______________

Analysis Date: ______________________**Analysis Prepared by:** ______________________________

TRAFFIC FLOW CONSIDERATIONS:	**YES**	**NO**
1. Does congestion routinely recur in the merge area because the traffic demand on the freeway exceeds the capacity of the merge area?	☐	☐
2. Does the freeway regularly operate at speeds less than 50 mph for at least a half-hour period?	☐	☐
3. Does the **ramp** have a minimum flow rate of at least 300 vph during the peak periods?	☐	☐
4. Does the measured hourly flow rate of traffic in the two right-most **freeway lanes** exceed the threshold shown in Attachment A?	☐	☐
5. Does the measured hourly flow rate of the **ramp** plus the right-most **freeway lane** volume exceed the thresholds shown in Attachment B?	☐	☐
6. Does predictable, sporadic congestion occur on isolated sections of the freeway because of short-period peak traffic loads from special events or from severe peak loads of recreational traffic?	☐	☐
SAFETY CONSIDERATIONS:	**YES**	**NO**
7. Does the collision rate in the vicinity of the ramp exceed the mean collision rate in the metropolitan area?	☐	☐
8. Can the primary cause behind the majority of these collisions be attributed to congestion in the merge area?	☐	☐
9. Is there sufficient acceleration length to achieve an acceptable speed differential between the ramp traffic and freeway traffic (see Attachment C)?	☐	☐
10. Is there sufficient space to store vehicles between the stop line of the ramp meter without impeding traffic operations on the frontage road (see Attachment D)?	☐	☐
OTHER CONSIDERATIONS:	**YES**	**NO**
11. Is the ramp to be metered part of an existing ramp metering system?	☐	☐
12. Is ramp meter anticipated to cause significant increase in adjacent arterial traffic volume and/or congestion?	☐	☐
13. Is ramp meter likely to increase traffic diversion into adjacent neighborhoods?	☐	☐
14. Is ramp meter likely to increase noise level and/or negatively impact air quality in the vicinity of the ramp?	☐	☐

APPROVALS:

Recommend Approval: ☐ **YES** ☐**NO**

Remarks: ______________________________

____

Submitted
For Approval:______________________________ ____________________

District **Transportation Operations Engineer** **Date**

RECOMMENDATIONS APPROVED:

______________________________ ____________________

District Engineer **Date**

ATTACHMENT A:
Minimum Freeway Volume

Procedure

1. Measure/estimate the length of the acceleration lane.
2. Compute the average per lane freeway flow rate of the right two freeway lanes for each 15-minute interval of a typical day.
3. Using the Figure A- 1, determine the minimum freeway volume threshold that must be satisfied for the length of the ramp acceleration lane.
4. Compare the measured freeway flow rates to the minimum freeway volume threshold.

Data Requirements

- **Length of Ramp Acceleration Lane = ___________________** ft
- **Minimum Freeway Volume Threshold = ___________________** vphpl

Criteria

- If **Measured Freeway Flow Rates** $\geq$ **Minimum Freeway Volume Threshold**, then ramp metering **IS** likely to result in higher operating speeds on freeway.
- If **Measured Freeway Flow Rates** < **Minimum Freeway Volume Threshold**, then ramp metering **IS NOT** likely to result in higher running speeds on freeway.

Recommendation

The average traffic flow rate of the two right-most freeway lanes **DOES / DOES NOT** (strike through response that does not apply) exceed the minimum freeway volume threshold for implementing ramp metering.

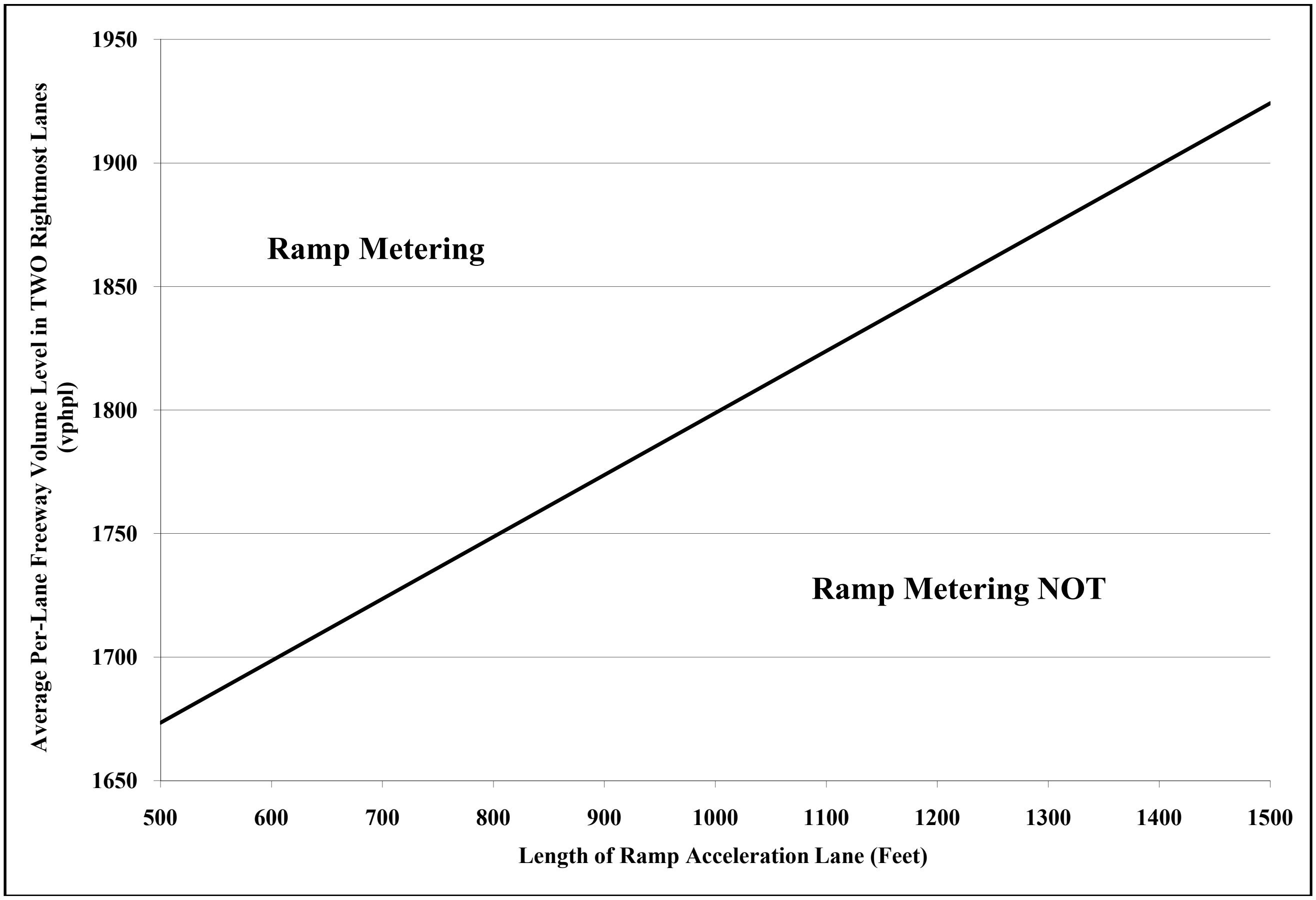

Figure A- 1. Minimum Freeway Volume Criteria for Installing Ramp Control Signal.

ATTACHMENT B:
Combination of Ramp and Freeway Traffic in Right-Most Lane

Procedure

1. Measure/estimate the length of the acceleration lane.
2. Compute the ramp plus right-most freeway lane flow rate for each 15-minute interval of a typical day.
3. Using the Figure B- 1, determine the minimum freeway volume threshold that must be satisfied for the length of the ramp acceleration lane.
4. Compare the measured ramp plus right-most freeway lane flow rate to the minimum freeway volume threshold.

Data Requirements

- **Length of Ramp Acceleration Lane = ___________________** ft
- **Minimum Combination Threshold =** ___________________ vph

Criteria

- If **Measured Combination Flow Rate** $\geq$ **Minimum Combination Threshold**, then ramp metering **IS** likely to result in higher operating speeds on freeway.
- If **Measured Combination Flow Rates** < **Minimum Combination Threshold**, then ramp metering **IS NOT** likely to result in higher running speeds on freeway.

Recommendation

The measured **combination** of ramp plus right-most freeway lane volume **DOES / DOES NOT** (strike through response that does not apply) exceed the minimum combination threshold for implementing ramp metering.

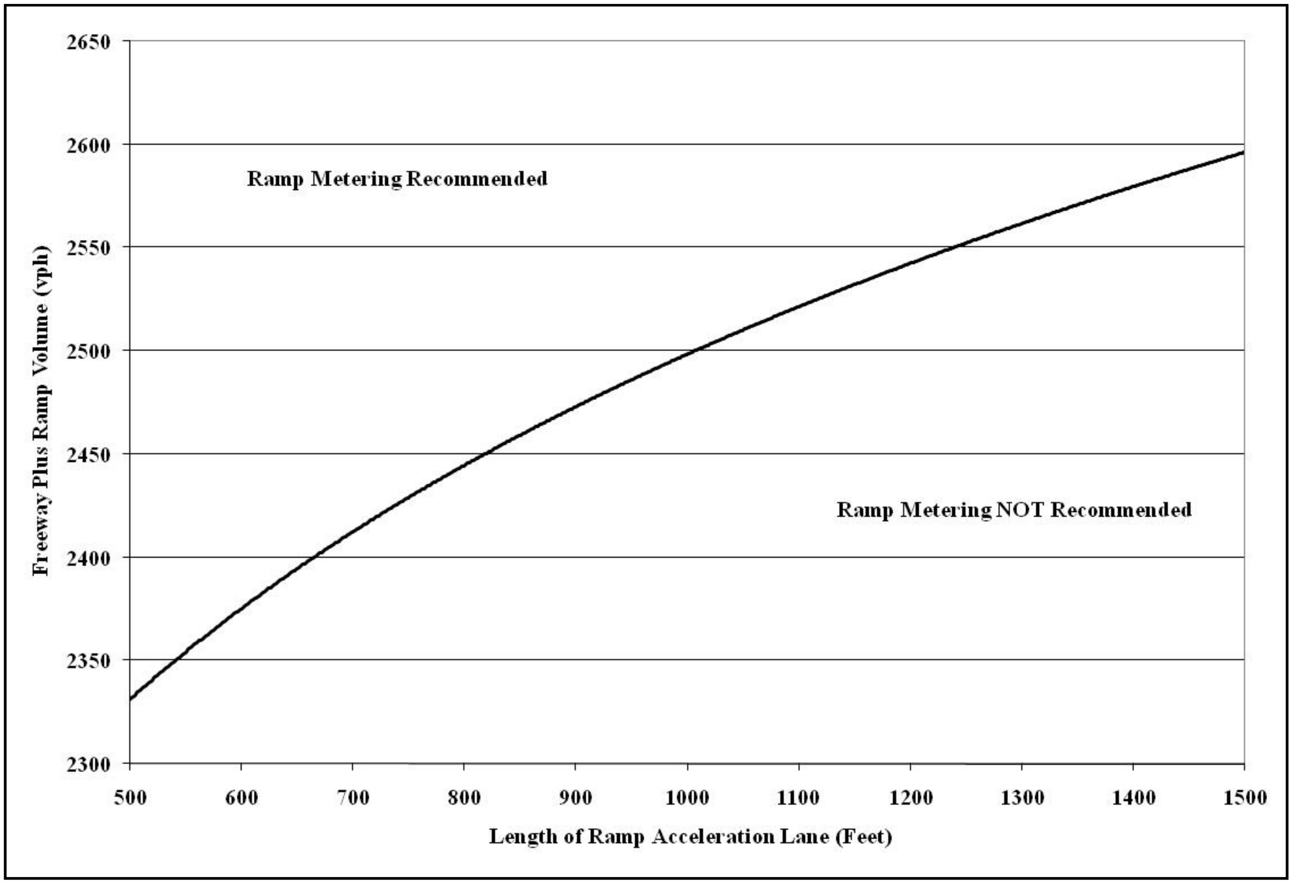

Figure B- 1. Combination Freeway Plus Ramp Volume Criteria for Installing Ramp Control Signal.

ATTACHMENT C:
Acceptable Speed Differential

Procedure

1. Obtain data requirements listed below.
2. Using Figure C-1, estimate the speed at which entering ramp traffic will be traveling when it arrives in the merge area of the freeway ($V_{R\text{-Acceleration}}$).
3. Using Figure C-2, determine the minimum speed that the entering ramp traffic must reach in order to maintain the desired minimum headway between the ramp and main lane traffic in the merge area ($V_{R\text{-Minimum}}$).
4. Apply criteria shown below.

Data Requirements

- **Acceleration Length**[1] **=** ___________________ ft
- **Grade of Ramp =**___________________ %
- **Minimum Headway to be Maintained between Ramp and Main Lane Traffic in Merge Area =** (select appropriate headway)
  ☐ **2 sec** ☐ **1.75 sec** ☐ **1.5 sec**
- **Free-Flow Speed on Freeway Main Lanes** = _____________ sec
- **Estimated Speed (in mph) of Entering Ramp Traffic in Freeway Merge Area after Accelerating from Stop due to Ramp Meter ($V_{R\text{-Acceleration}}$) =** _____________ mph (from Figure C-1)
- **Minimum Speed (in mph) of the Ramp Traffic in Order to Maintain Minimum Headway ($V_{R\text{-Minimum}}$) =** _____________ mph (from Figure C-2)

Criteria

- If $V_{R\text{-Acceleration}} \geq V_{R\text{-Minimum}}$, then there **IS** sufficient acceleration length to achieve an acceptable speed differential between the ramp traffic and freeway traffic.
- If $V_{R\text{-Acceleration}} < V_{R\text{-Minimum}}$, then there **IS NOT** sufficient acceleration length to achieve an acceptable speed differential between the ramp traffic and freeway traffic.

Recommendation

There **IS** / **IS NOT** (strike through response that does not apply) sufficient acceleration length to achieve an acceptable speed differential between the ramp traffic and freeway traffic.

[1] Measured from the stop line of the proposed ramp meter to the merge point on the freeway.

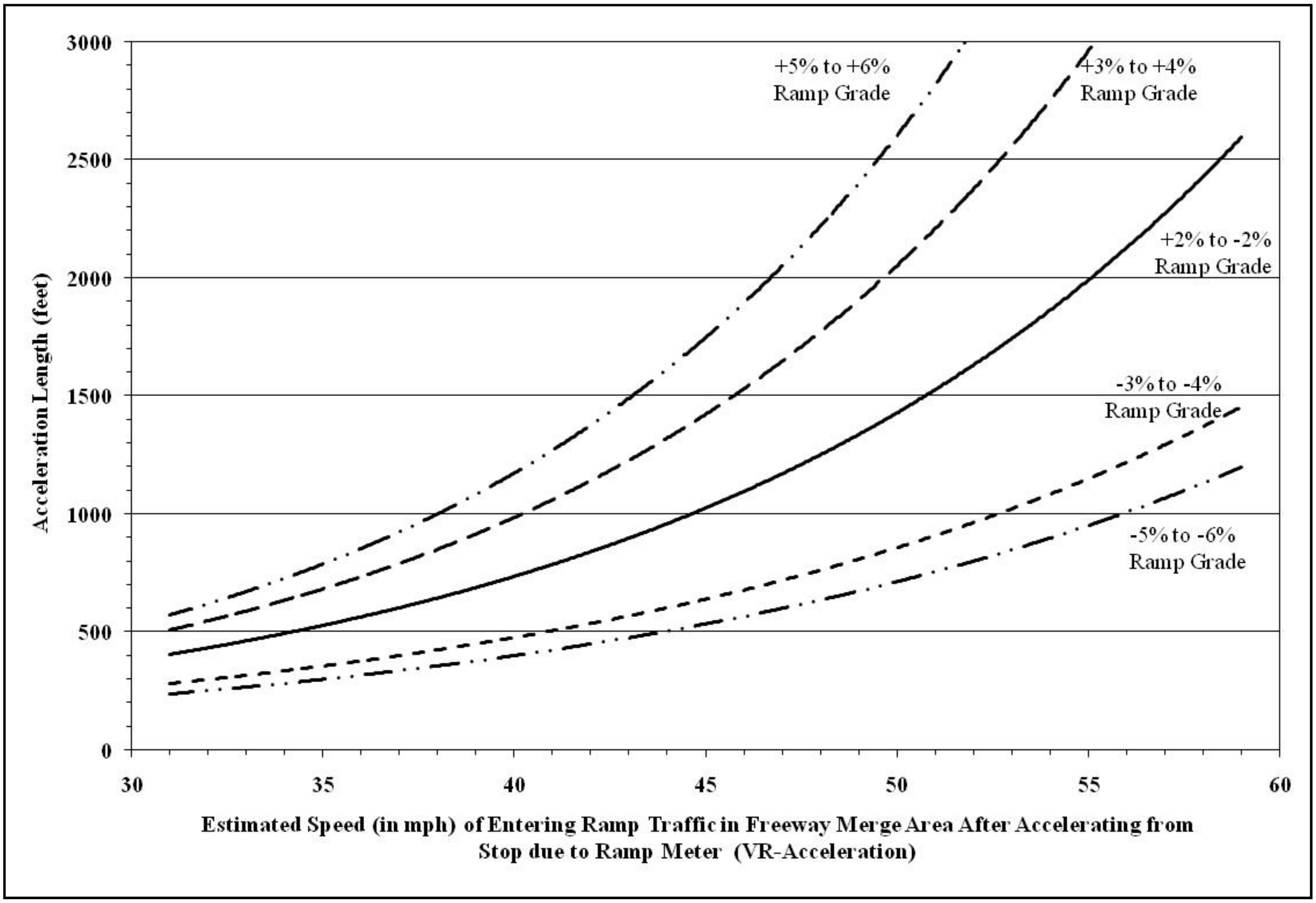

Figure C-1. Estimated Speed of Ramp Traffic in the Freeway Merge Area after Vehicle Accelerates from Stop at the Ramp Meter.

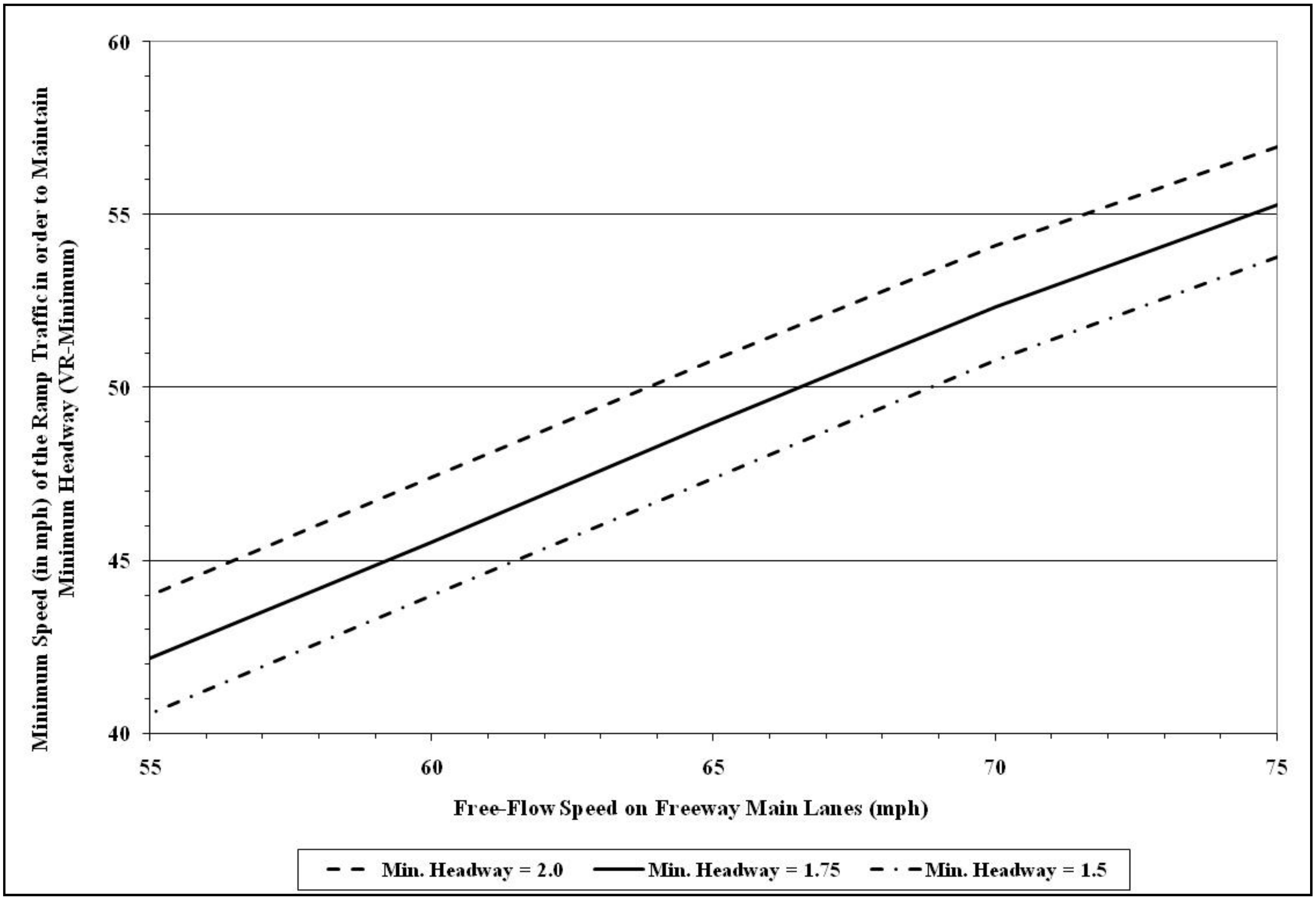

Figure C-2. Minimum Speed of Ramp Traffic in order to Maintain Minimum Headway between Entering Ramp Traffic and Main Lane Freeway Traffic.

ATTACHMENT D:
RAMP METER STORAGE REQUIREMENT

Data

Ramp Demand[1] = ___________________ vph

Maximum Wait Time in Queue = 1 min / 2 min (strikeout the one that does not apply)

Required Ramp Meter Storage Length = ______________________ feet (from Figure D- 1**)**

Available Storage Space[2] = __________________ feet (as measured in field)

Criteria

If **Available Storage Space ≥ Required Ramp Meter Storage Space**, then sufficient storage space exits to install ramp meter.

Recommendation

Sufficient space **DOES / DOES NOT** (strike through response that does not apply) exist to permit storage of ramp demand at desirable wait times.

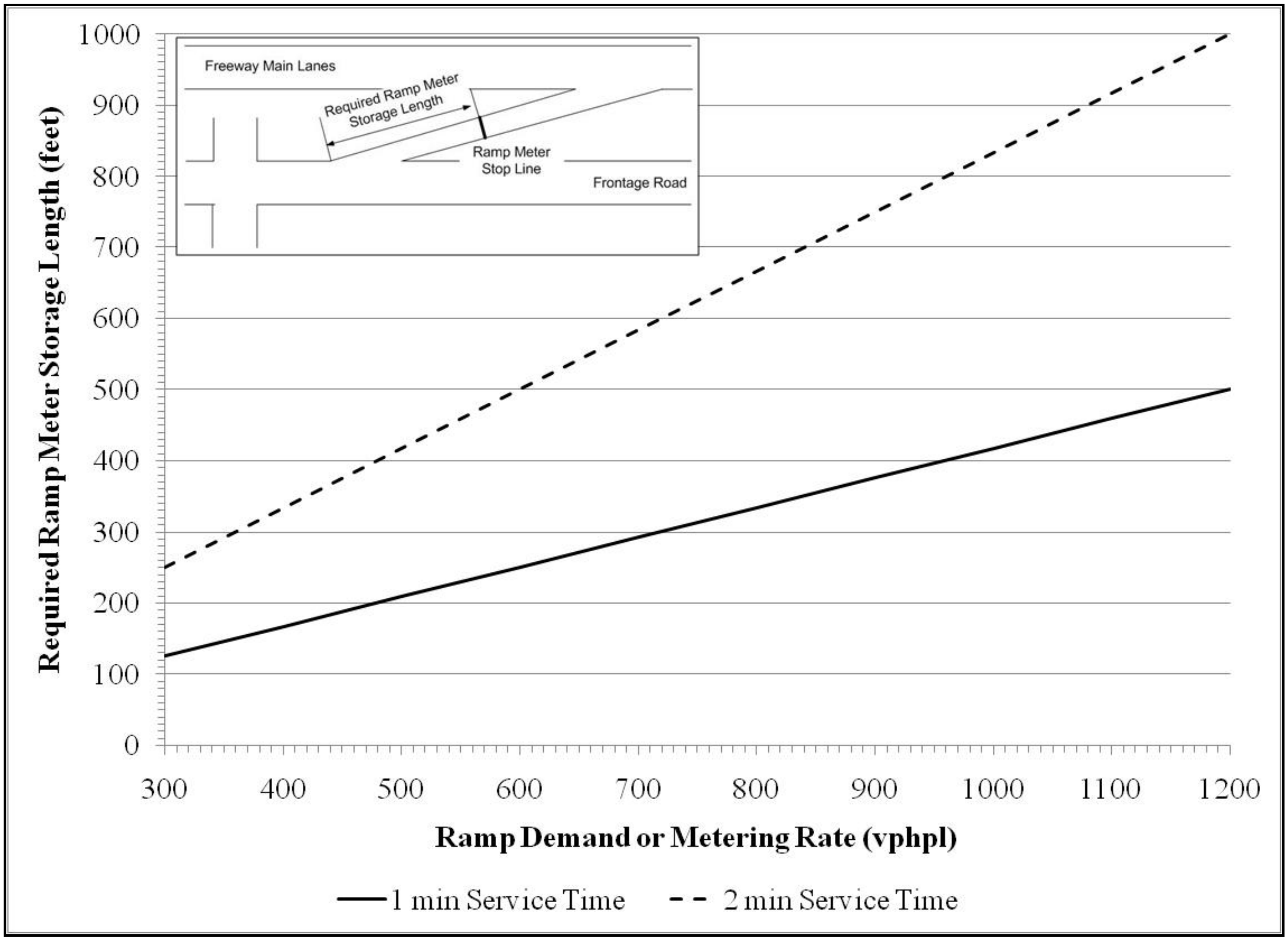

Figure D- 1. Required Storage Length to Accommodate Ramp Demand.

[1] Ramp demand = Peak 15-min Demand count *4
[2] Measured from the stop line to the further point upstream that vehicles can be stored without interfering with operation of frontage road. Determined from field.

Appendix B

Ramp Control Signal Removal Authorization Form

Ramp Control Signal Removal Authorization Form

Freeway Name: _________________________ **Ramp Name:** ____________________ **Direction of Travel**: ________

Freeway Control Section: ______________________ **Freeway Reference Marker**: _____________________

City Name: ______________________ **County Name:** _________________________ **District:** __________________

Analysis Date: _________________________________ **Analysis Prepared by:** ___________________________

Instructions:

Removal of a ramp control signal may be considered when one or more of the following situations exist.

Criteria:	**YES**	**NO**
♦ Has the freeway been reconstructed so that the ramp is now the beginning of a new freeway lane?	☐	☐
♦ Do traffic demands on the ramp still exceed the minimum ramp volume threshold for installing a ramp meter (300 vph)?	☐	☐
♦ Does the rate of crashes in the merge area exceed the mean crash rate of other ramps that use ramp control signals?	☐	☐
♦ Is there an inordinate amount of rear-end crashes on the freeway or frontage road caused by congestion at the ramp meter?	☐	☐
♦ During the peak operating conditions, is the meter availability[1] much less than 70 percent?	☐	☐
♦ After reconstruction, are prevailing speeds on the freeway (during normal operations) expected to exceed 50 mph for the entire day?	☐	☐
♦ Do the annual costs of operating and maintaining the ramp control signal exceed the estimated benefits to freeway traffic?	☐	☐
♦ Do delays to ramp traffic exceed the threshold established by the district engineer and other measures to reduce delay have proved unsuccessful?	☐	☐
♦ Has driver noncompliance at the ramp reached an unacceptable level and increased enforcement has failed to correct the noncompliance issue?	☐	☐

APPROVALS:

Recommend Removal of Ramp Control Signal: ☐ **YES** ☐ **NO**

Remarks: ____

____

Submitted
For Approval:_______________________________________ ____________________
District Transportation Operations Engineer Date

RECOMMENDATIONS APPROVED:

____ ____________________
District Engineer **Date**

[1] Meter Availability is computed by dividing the amount of time that the signal is cycling by the total operating time. The amount of time that signal is cycling can be computed by subtracting the total amount of duration that the ramp control signal is flushing and in the startup mode from total operating time (e.g., 1-hour for the peak hour).

Appendix C

Suggested Freeway Performance Measures

Table C-1. Recommended Core Measures for Use in Measuring the Effectiveness of Freeway Operations Improvements.

Performance Metric	Definition	Units	Geographic Scale	Time Scale
Average (Typical) Congestion Conditions (Quality of Service)				
Travel Time	The average time consumed by vehicles traversing a fixed distance of freeway	Minutes	Specific points on a section or a representative trip only; separately for GP[1] and HOV[2] lanes	Peak hour, AM/PM peak periods, midday, daily
Travel Time Index	The ratio of actual travel rate to ideal travel rate[a]	None; minimum value = 1.0	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, AM/PM peak periods, midday, daily
Total Delay, Vehicles	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions	Vehicle-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, AM/PM peak periods, midday, daily
Total Delay, Persons	The excess travel time used on a trip, facility, or freeway segment beyond what would occur under ideal conditions	Person-hours	Section and areawide as a minimum; separately for GP and HOV lanes	Peak hour, AM/PM peak periods, midday, daily
Delay per Vehicle	Total freeway delay divided by the number of vehicles using the freeway	Hours (vehicle-hours per vehicle)	Section and areawide	Peak hour, AM/PM peak periods, daily
Spatial Extent of Congestion No. 1	Percent of Freeway VMT[3] with Average Section Speeds < 50 mph	Percent	Section and areawide	Peak hour, AM/PM peak periods
Spatial Extent of Congestion No. 2	Percent of Freeway VMT with Average Section Speeds < 30 mph	Percent	Section and areawide	Peak hour, AM/PM peak periods
Temporal Extent of Congestion No. 1	Percent of Day with Average Freeway Section Speeds < 50 mph	Percent	Section and areawide	Peak hour, AM/PM peak periods
Temporal Extent of Congestion No.2	Percent of Day with Average Freeway Section Speeds < 30 mph	Percent	Section and areawide	Peak hour, AM/PM peak periods
Bottleneck ("Recurring" Delay)	Delay that is attributable to bottlenecks	Vehicle-hours	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Maximum Freeway Queue Length	The longest continuous queues (vehicle speeds < 30 mph over a 5-minute period) resulting from a physical or event-related bottleneck	Miles	Section	N/A
Ramp Delay	Delay that occurs at ramp meters	Vehicle-hours	Individual ramps and section as a minimum	Peak hour, AM/PM peak period, midday, daily

Table C-1. Recommended Core Measures for Use in Measuring the Effectiveness of Freeway Operations Improvements (Continued).

Performance Metric	Definition	Units	Geographic Scale	Time Scale
Reliability (Quality of Service)				
Buffer Index	The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	Percent	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Planning Time Index	The 95th percentile Travel Time Index	None; minimum value = 1.0	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Throughput (Quality of Service)				
Throughput-Vehicle	Number of vehicles traversing a freeway in vehicles	Vehicles per unit time	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Throughput – Persons	Number of persons traversing a freeway	Person per unit time	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Vehicle-Miles of Travel	The product of the number of vehicles traveling over a length of freeway, times the length of the freeway	Vehicle-miles	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Lost Highway Productivity	Lost capacity due to the flow breakdown – the difference between the measured volume on a freeway segment under congested flow versus the maximum capacity for that segment	Vehicles per hour	Section and areawide	Peak hour, AM/PM peak period, midday, daily
Safety (Quality of Service)				
Total Crashes	Freeway crashes as defined by the state, i.e., those for which a police accident report form is generated	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually
Fatal Crashes	Freeway crashes as defined by the state, i.e., those for which a police accident report form is generated, where at least one fatality occurred	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually
Overall Crash Rate	Total freeway crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually

Table C-1. Recommended Core Measures for Use in Measuring the Effectiveness of Freeway Operations Improvements (Continued).

Performance Metric	Definition	Units	Geographic Scale	Time Scale
Safety (Quality of Service)				
Fatality Crash Rate	Total freeway fatal crashes divided by freeway VMT for the time period considered	Number per 100 million vehicle-miles	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually
Secondary Crashes	A police-reported crash that occurs in the presence of an earlier crash[b]	Number	All safety measures computed areawide; section level may be computed if multiple years are used	All safety measures computed annually

[a] Travel rate is the inverse of speed, measured in minutes per mile. The "ideal travel rate" is the rate that occurs at the free-flow speed of a facility, or a fixed value set for all facilities that is meant to indicate ideal conditions or "unconstrained."

[b] "in the presence" may be defined as the time period before the first incident is cleared from the roadway and/or the queue from the first incident still exists, even if the vehicles were removed.

[1]GP=General Purpose

[2]HOV= High Occupancy Vehicle

[3]VMT = Vehicle Miles Traveled