Case Studies of U.S. Freeway-to-Freeway Ramp and Mainline Metering and Suggested Policies for Washington State

ELDON L. JACOBSON AND JACKIE LANDSMAN

To mitigate increasing traffic congestion and to improve highway safety, state departments of transportation have come up with some innovative strategies for optimizing the efficiency of congested freeway sections. Two such strategies are freeway-to-freeway ramp metering and mainline metering. Freeway-to-freeway ramp metering involves installing traffic signals (either on the side of the roadway or overhead) on the ramps found at freeway-to-freeway interchanges. Mainline metering involves installing traffic signals (usually overhead) on the mainline of a freeway. Some examples of freeway-to-freeway ramp metering in the United States, namely, in Minnesota and California, are examined and the advantages and disadvantages of freeway-to-freeway ramp metering are discussed. The implementation and operational issues of the only known operating example of mainline metering in the western United States are also discussed. A complete and thorough analysis should take place before the installation of any freeway-to-freeway or mainline metering system. This analysis is needed to ensure that safety is maintained and that environmental concerns are addressed. The suggested policy on freeway-to-freeway ramp metering is to install meters on freeway-to-freeway ramps where system performance and efficiency would be improved. The suggested policy on mainline metering is to install mainline meters on freeways approaching bottleneck locations where analysis indicates that improved traffic operations would result. Guidelines for both metering types are given.

During the past few decades, traffic patterns have changed dramatically as commuters have moved farther away from central business districts and into the suburbs in search of, among other things, affordable single-family housing. This trend has contributed to the increase in suburban traffic congestion and also has resulted in longer commutes and an increase in total highway miles traveled. To mitigate the increasing congestion and to improve highway safety, state departments of transportation have come up with some innovative strategies for optimizing the efficiency of congested freeway sections. Two such strategies are freeway-to-freeway ramp metering and mainline metering.

Freeway-to-freeway ramp metering consists of installing traffic signals (either on the side of the roadway or overhead) on the ramps found at freeway-to-freeway interchanges. Mainline metering consists of installing traffic signals (usually overhead) on the mainline of a freeway.

The operational success of a number of freeway-to-freeway ramp and mainline metering systems currently installed around the country is discussed. Policies and guidelines concerning the installation and operation of freeway-to-freeway ramp metering and mainline metering for Washington State are suggested.

E. L. Jacobson, Washington State Department of Transportation, c/o Washington State Transportation Center, 1107 NE 45th St., Suite 535, Seattle, Wash. 98105-4631. J. Landsman, FHWA, 211 Main Street, Room 1100, San Francisco, Calif. 94105.

FREEWAY-TO-FREEWAY RAMP METERING CASE STUDIES

Examples of freeway-to-freeway ramp metering are increasing throughout the United States. The majority of the installations are found in California and Minnesota. In addition, Washington State currently has two freeway-to-freeway ramp metering operations at the Swamp Creek interchange north of Seattle (northbound (I-405 to southbound I-5 and southbound SR-525 to southbound I-5). The Tacoma, Washington, area will have its first freeway-to-freeway ramp metering operation in the spring of 1994 at the SR-512 interchange on I-5 (westbound SR-512 to southbound I-5). The Vancouver, Washington, area is planning to install ramp metering at the SR-14 interchange (westbound SR-14 to southbound I-5). The following sections document in greater detail the status of a number of freeway-to-freeway metering sites.

Los Angeles, California

In Los Angeles, where a large number of typical ramp metering installations are operated, only a few interchanges have freeway-to-freeway ramps that are metered. The first was at the interchange of I-5 and I-110 (southbound I-5 to southbound I-110). Additional freeway-to-freeway ramp metering operations have been set up with the completion of the new Century Freeway.

The direct connection between southbound I-5 and southbound I-110 (see Figure 1) typically supported high traffic volumes. When one of the two lanes on this facility had to be closed because of regular rock slides, queues on the southbound I-5 connector became the norm [with maximum traffic volumes of 2,300 vehicles per hour (vph) for the single lane]. In May 1992, after a solution to the slide problem was found, the second lane was reopened, and a two-lane ramp metering operation was installed on the connector to help manage the heavy traffic flow onto southbound I-110. With the reopened lane, flow during the off-peak period (when the meters are off) has improved considerably, and virtually no queuing on I-5 is caused by this movement. However, when the meters are on during the peak period, considerable queues still occur on the connector [with almost 1 km (0.5 mi) of two-lane storage available] and on southbound I-5 (although the queues are now somewhat shorter because of the storage provided by the reopened lane). The two-lane metering is turned on during

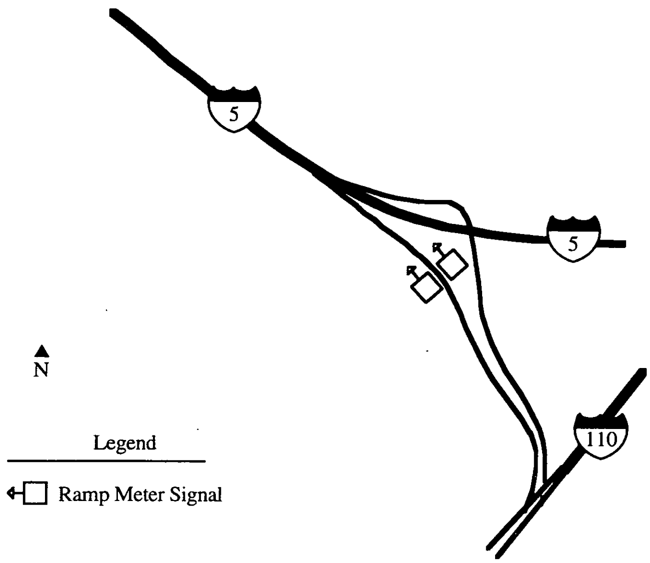

FIGURE 1 Interchange of I-5 and I-110, Los Angeles.

the morning peak period. Although the metering is set to operate at a maximum of 1,800 vph for the two lanes, actual maximum traffic volumes are around 1,600 vph. There is no high-occupancy-vehicle (HOV) bypass lane on this ramp.

Traffic flow on southbound I-110 at the interchange may have improved slightly with the metering (no before-and-after study has been done yet), but before the additional lane was opened, the I-5 connector itself acted as a meter onto I-110. Because only one lane of traffic was allowed onto southbound I-110, a serious bottleneck was avoided at this location. However, if the widened connector had not been metered, the additional traffic accessing I-110 probably would have seriously impeded southbound I-110 traffic and would have caused extensive queuing on southbound I-110.

Minneapolis, Minnesota

Minneapolis has the largest number of freeway-to-freeway ramp metering operations in the United States. Its two earliest installations were activated in 1971 at the interchange of Trunk Highway (TH) 36 and I-35E (eastbound and westbound TH-36 to southbound I-35E). Since then, an additional 25 freeway-to-freeway ramp metering installations have been activated throughout the Minneapolis–St. Paul metropolitan area. Most commonly, the Minnesota Department of Transportation (MnDOT) has initiated the metering in conjunction with other roadway improvements. MnDOT's primary objective often has been to encourage route diversion away from onerous merges, especially where alternative routes have been identified. Another objective is to manage and control the queuing at certain interchanges. Several in-depth case studies follow. Some of these cases involve metered on ramps upstream of the freeway-to-freeway ramp metering, so some vehicles may be metered twice on one trip.

Eastbound I-94 to Southbound TH-65

In 1974 ramp control was initiated from eastbound I-94, a six-lane freeway, to southbound TH-65, a four-lane freeway (see Figure 2), to reduce the heavy congestion that was occurring downstream of this location and to improve the flow of the corridor in general. Before implementation, the two-lane ramp had carried 1,080 vph during the p.m. peak hour. After the metering was turned on and both lanes had been metered, the volumes on the ramp dropped to 690 vph during the p.m. peak. MnDOT estimates that over two-thirds of the reduction is caused by route diversion. Typical delays on the ramp are over 1 min, but they can reach up to 8 min with 0.5-km (0.25-mi) queues.

The last in-depth analysis of this metering operation showed that even though volumes had increased by 17 percent, the southbound peak-hour speeds on TH-65 had increased by 29 percent since metering had been initiated. This high performance level on the freeway has led to few complaints and high driver compliance with the metering. The study also found that peak-period accidents had been reduced by 21 percent since the system began operation.

Eastbound and Westbound I-494 to Southbound and Northbound I-35W

All four I-494 ramps were metered to the four-lane I-35W in 1975 as part of the Urban Corridors Demonstration Program in Minneapolis. The volumes on these ramps were consequently reduced by approximately 20 to 25 percent after metering had been initiated. Volumes on the ramps to northbound I-35W (see Figure 3) have been reduced from 650 to approximately 500 vph, and queuing associated with this volume has not been a problem. Average delays are less than 1 min. However, the I-494 ramps to southbound I-35W (see Figure 4) maintain higher volumes and, consequently, longer queues. In particular, the eastbound to southbound movement resulted in queues that backed up ahead of the ramp and extended onto the shoulder of I-494. This situation created a further problem when some drivers attempted to cut in at the last moment, rather than wait in line. To mitigate this problem, the ramp was widened to two lanes to increase storage capacity. The westbound to southbound movement experienced similar problems; however, in that situation widening was not possible. The ramp is monitored closely by operators so that the metering rate can be increased when a problem begins to develop.

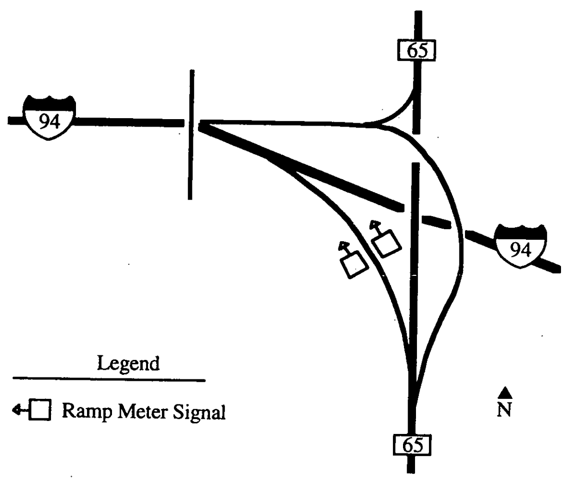

FIGURE 2 Interchange of I-94 and TH-65, Minneapolis.

Metering at this location is considered to be partly responsible for the 38 percent increase in speeds on northbound I-35W, as well as for an increase in speed on southbound I-35W. Even with the problems described above, the number of accidents at this location has decreased.

Eastbound and Westbound TH-13 to Northbound I-35W

The two direct connector ramps (see Figure 5), eastbound and westbound TH-13 to northbound I-35W, were incorporated into the freeway management system as part of the Urban Corridors Demonstration Program. Although the volumes were not extremely high on these ramps before metering (690 vph eastbound to northbound and 510 vph westbound to northbound), the eastbound-to-northbound ramp was limited by its low-speed cloverleaf design. After metering had been initiated, volumes decreased by approximately 100 vph on each ramp. Average vehicle delays range between 3 and 4 min; however, these vehicle delays are highly dependent on the status of alternative routes. When an incident occurs that prevents or discourages diversion, delays at this interchange can reach 15 min, with queues on the shoulders for up to 1 mi. Because TH-13 is not a high-volume roadway, the ramp metering has not demonstrated a safety problem.

Just downstream of this interchange, northbound I-35W crosses the Minnesota River. By metering the TH-13 direct connectors,

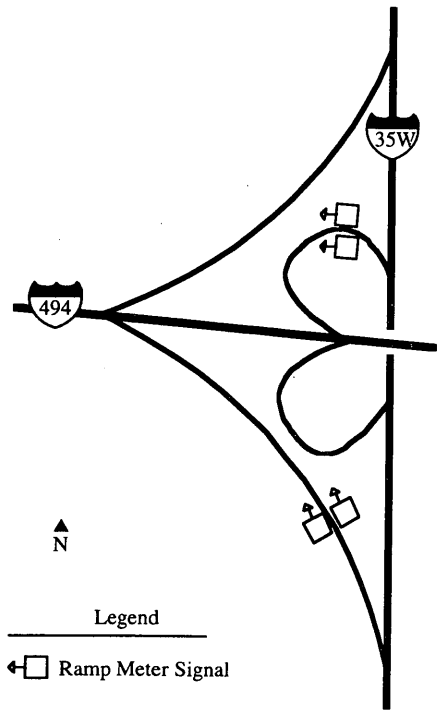

FIGURE 4 Interchange of I-494 and I-35W (southbound metered ramps), Minneapolis.

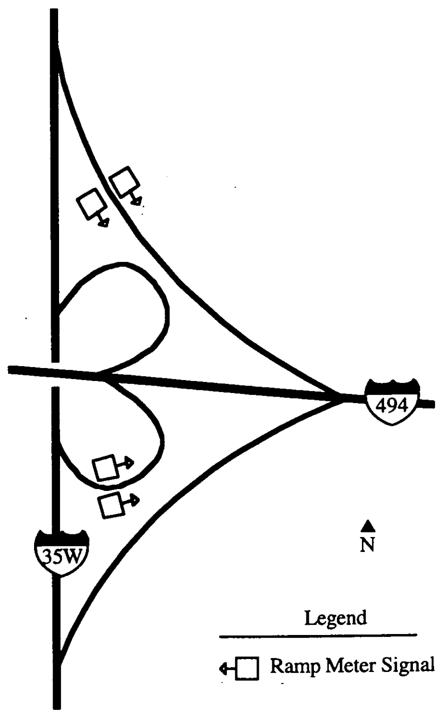

FIGURE 3 Interchange of I-494 and I-35W (northbound metered ramps), Minneapolis.

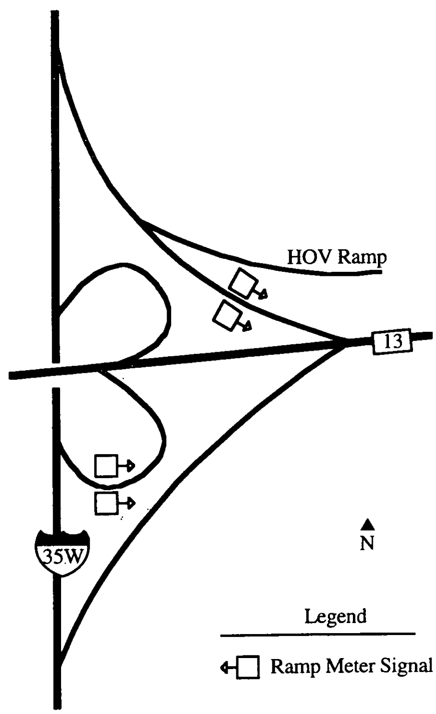

FIGURE 5 Interchange of I-35W and TH-13 (east half of interchange), Minneapolis.

MnDOT has kept this corridor open with a minimum of congestion over the bridge. The metering is considered essential to providing optimal flow through the section and has met with high motorist compliance in spite of queuing on the ramps.

San Diego, California

San Diego began using freeway-to-freeway ramp metering in 1971; the first installation was at the interchange of SR-15 and SR-94 (southbound SR-15 to westbound SR-94). Since then, three more installations have been added, two of which feed SR-94 and the third I-8. The initial justification for these installations was to better manage the queuing and the delay that was occurring at these interchanges and to better manage the freeway system in general. A more detailed description of two of these locations follows.

Southbound SR-67 to Westbound I-8

The most recent direct connector metering installation in San Diego (1985) (see Figure 6) is at the interchange of SR-67 and I-8 (southbound SR-67 to westbound I-8). This three-lane metering was installed to relieve congestion on I-8 just downstream of the interchange and to improve traffic flow throughout the area. Before metering, this section of I-8 was frequently congested with long queues that extended upstream from the interchange. Since the metering was turned on, the flow downstream on I-8 has averaged 2,500 vehicles per hour per lane (vphpl), and speeds have averaged 100 km/hr (60 mph). Average weekday traffic has dropped from 37,000 vehicles before metering was installed to 30,000 vehicles after metering was activated.

This freeway-to-freeway ramp metering operates almost as mainline ramp metering. Because SR-67 ends at a city arterial street, which is just downstream of the metering location, the majority of the traffic on southbound SR-67 at the I-8 interchange uses the connector to access westbound I-8. There is no HOV bypass lane at this location. There is almost unlimited storage length, because the queues occur on the freeway mainline of SR-67. During the peak hour the maximum metered traffic volume is 2,300 vph for the three lanes.

Although no formal before-and-after study has been completed, the consensus within the Traffic Systems Branch of the California Department of Transportation (Caltrans) is that the metering strategy at this interchange has been very successful. The effectiveness of the metering was clearly demonstrated a number of years ago when an electrical malfunction caused the meters to discharge cars more rapidly onto I-8 than the normal metering rate. Queues of several miles formed on I-8 because of this malfunction, causing long delays for those traveling westbound on I-8, as well as for those attempting to reach I-8 from the southbound SR-67 ramp. Although the event was not planned, it served to educate the public on the benefits of metering, and consequently public acceptance improved considerably.

Because SR-67 ends at I-8, the problem of traffic on SR-67 speeding by metered, stopped traffic has not occurred. On ramps to southbound SR-67 upstream of the SR-67/I-8 interchange are not currently metered.

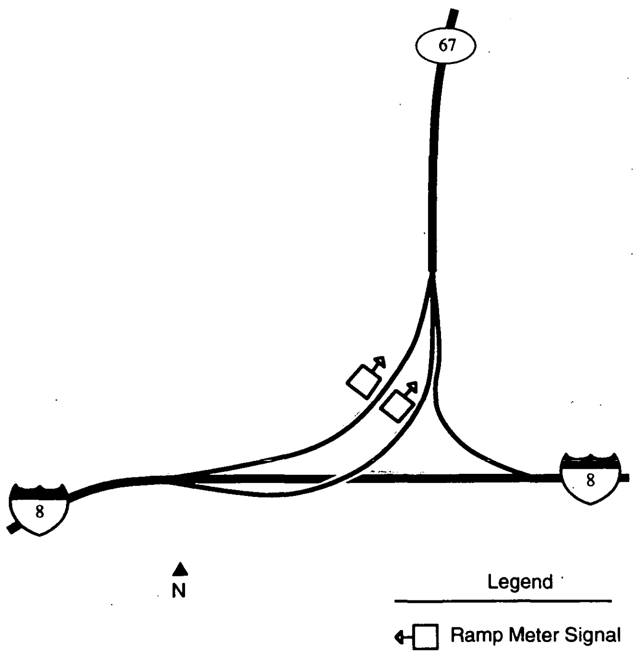

FIGURE 6 Interchange of I-8 and SR-67, San Diego.

Westbound SR-94 to Southbound SR-94 (Extension of Southbound SR-125)

The metering for this direct connector (see Figure 7) was turned on in May 1978 to relieve some of the congestion and queuing through the SR-94 interchange. In addition, metering was added to the cross street feeding the southbound SR-125 on ramp, which merges with the westbound SR-94 direct connector just before their confluence with southbound SR-125. Metering on both routes is operated by an automated, traffic-responsive system on the basis of mainline volumes, so the metering is typically on only during peak periods. To encourage carpooling and to improve bus service through the interchange, the direct connector also features a peak-period, inside HOV lane in addition to the two regular lanes. During the off peak, the HOV lane is not used as a travel lane. On ramps to westbound SR-94 upstream of the SR-94/SR-125 interchange are not currently metered. All three lanes (including the HOV lane) are metered.

When the metering on the direct connector was first activated, the ramp carried approximately 1,900 vph during the peak hour, with an average wait of 1 min and a maximum wait of about 3 min. Today the daily volume on the three-lane ramp is approximately 28,000 vehicles (peak-hour volume of 2,900 vph), and the maximum wait during the peak period can exceed 10 min. In spite of the high ramp delays, there have been very few complaints, and responses to the metering have continued to be positive. Caltrans reasons that public acceptance has remained high largely because of the level of service provided on the freeway, in particular, the high speeds that are maintained beyond the metering. The time savings attributed to metering are purported to be up to 20 min for some home-to-work commute trips. Queues do extend back on the connector because of the metering; however, these queues also existed before the metering, and no safety problems have surfaced because of the metering itself.

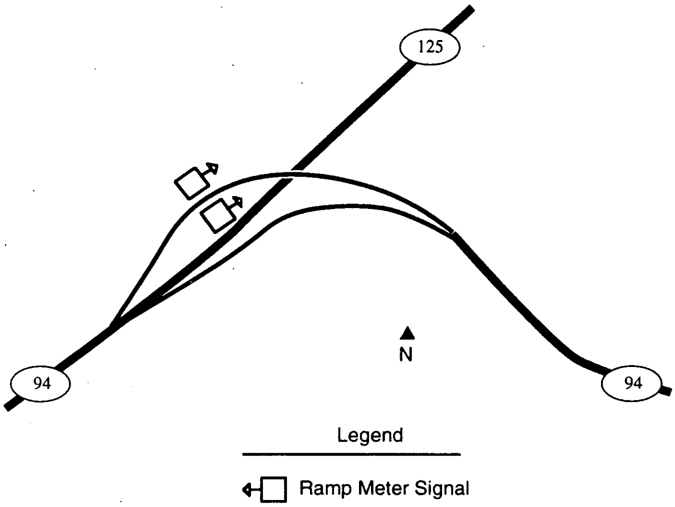

FIGURE 7 Interchange of SR-94 and SR-125, San Diego.

Discussion of Case Studies

So far, Caltrans' policy has been to be very selective in instituting freeway-to-freeway ramp metering, and all the installations it has initiated thus far have been successful not only operationally, but also in the public's opinion. Because of the public's increased frustration with traffic congestion, a high level of acceptance has been shown for traffic management strategies that improve the overall quality of the commute. When negative feedback has been encountered, Caltrans has tried to remedy the situation. Caltrans has not done much in the way of public education for its ramp metering system. It has instead relied on improved system operation to communicate the benefits of freeway-to-freeway ramp metering. Most of Caltrans' districts have a strong relationship with the traffic reporting media, and these ties have been used to educate the media, and consequently the public, about the strategies under way.

MnDOT has the most extensive system of freeway-to-freeway ramp metering, and its continued use of this management strategy is an indicator of its faith in the strategy's effectiveness. MnDOT has conducted several studies that have quantified the benefits of this type of metering. It has been concluded that, on average, throughput downstream of the metering increases by 300 to 400 vphpl, speed increases by approximately 27 percent, and total accidents decrease by 38 to 40 percent. The Minnesota freeway system consists of a typical spoke-and-wheel design; thus, at least one alternative route is usually available for most trips. Route diversion has been encouraged in especially congested areas with strategic metering placement. MnDOT has maintained strong public support through a concentrated public information effort, along with strong media support.

MAINLINE METERING CASE STUDY

The only known operating example of mainline metering in the western United States is westbound I-80 approaching the San Francisco–Oakland Bay Bridge. Two locations in the eastern United States with mainline metering are the Baltimore Harbor Tunnel in Maryland and the Hampton Roads Bridge-Tunnel in Virginia (*1*). Mainline metering was apparently first implemented in the New York City area by the local Port Authority in the early 1960s. The Boston, Massachusetts, area plans to install mainline metering on I-90 approaching the Harbor Tunnel. Washington State Department of Transportation (WSDOT) is studying the possibility of installing mainline metering on the highway approaching the Tacoma Narrows Bridge.

San Francisco, California

Westbound I-80 at San Francisco–Oakland Bay Bridge

This mainline metering facility located westbound I-80 at the San Francisco–Oakland Bay Bridge (see Figure 8) is a unique system because the meters are located just downstream of a 22-bay toll plaza. Westbound traffic approaching the bridge passes through the toll plaza and is then metered so that the 22 lanes of traffic can be narrowed to five lanes as efficiently as possible. HOV lanes that allow HOVs to bypass the traffic queues are also provided (*2*).

The metering helps delay extensive queuing during the peak period; however, queues during this time are inevitable, and wait time at the metered area can reach 30 min. On the other hand, with the meters off, queuing occurs on the bridge instead of at the metered area and the delays exceed those that occur when the metering is on. Public opinion of this metering has been quite good, considering the long delays. Motorists apparently realize that the metering does save them time. One peripheral benefit of the metering system is that heavy vehicles are able to reach normal speed before arriving at the uphill grade that approaches the bridge. Before the metering system was installed, trucks had a tougher time because the bottleneck occurred near the bottom of the uphill grade.

The San Francisco–Oakland Bay Bridge mainline metering is operated during peak traffic periods, which vary depending on traffic volumes. The metering is operated also outside peak periods whenever the traffic volumes reach a preselected level or

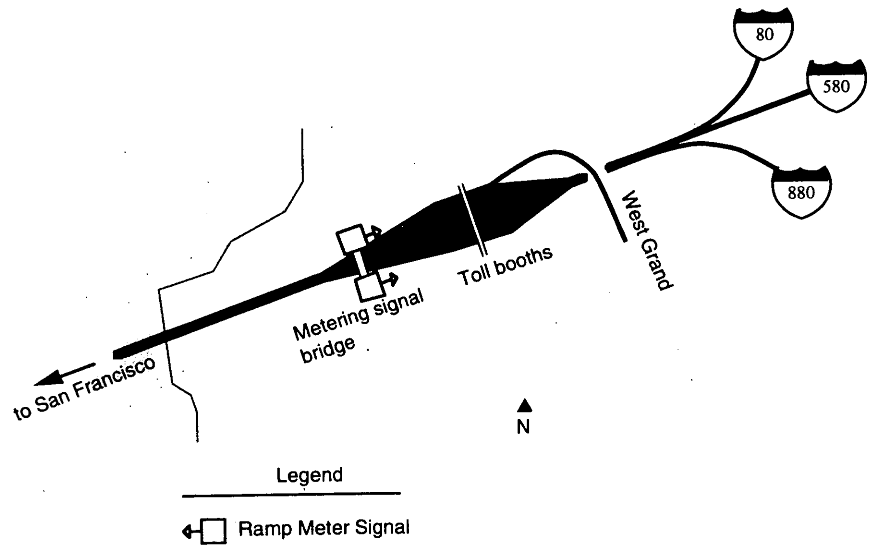

FIGURE 8 Mainline metering on I-80, Oakland (westbound direction).

when an incident on the bridge blocks the traffic lanes. Thus, tow trucks can bypass the traffic queue created by the metering and get to incidents quickly, thereby allowing them to clear the roadway faster. Emergency vehicles likewise avoid being stuck in the usual queues that form upstream of an incident location. The metering is turned on and off by the local Caltrans traffic operations center.

Discussion of Case Study

Mainline metering has both advantages and disadvantages. The main advantage is better traffic operations downstream of the metering. A disadvantage is the possible political opposition from some motorists traveling the corridor. So far mainline metering has been implemented or planned for locations approaching a major traffic bottleneck, such as a bridge or tunnel.

Implementation Issues

One of the theories behind implementing mainline metering before a bottleneck section is that metering maintains a more orderly progression through the constrained section. This, in effect, increases the traffic capacity and flow through the bottleneck. The conditions that exist at most bottlenecks today consist of heavy weaving and braking maneuvers, which are often dictated by aggressive drivers who jockey for a better position in the queue and force others to brake or weave out of the way. Mainline metering can smooth this traffic flow and improve the operational efficiency of the system, not just downstream of the meters, but for the system as a whole.

Another possible use of mainline metering involves the equitable distribution of delay. If most of the on ramps on a mainline for which metering has been proposed have ramp metering that causes drivers to wait in line, the equitable approach is to meter the mainline upstream of the ramp metering so that the mainline drivers also have to wait in line. However, the drivers passing through the mainline metering would probably be traveling farther.

As an example, if mainline metering were installed on southbound I-5 south of Marysville (in Washington State north of Seattle), three traffic lanes would feed into three traffic lanes. Given the normal, maximum metering rate of 900 vphpl, the freeway downstream of the mainline metering would have very little congestion (maximum capacity of 2,000+ vphl). The metering capacity could be increased by allowing two vehicles to pass during each green cycle or by widening the road to install additional metered lanes. The unused freeway downstream capacity would allow more traffic to be metered onto the freeway at downstream on ramps. Of course, upstream queues would probably develop. The queue lengths would vary depending on the approaching traffic volumes.

Some possible long-term land use impacts also may be associated with mainline metering. If a corridor contained ramp metering but no mainline metering, people might move farther from the suburban area to avoid the metering, continuing sprawl. Conversely, if a corridor contained both mainline metering (with its ensuing traffic backup) and ramp metering, a person's choice of where to live would be influenced by factors other than freeway metering.

Because it can be associated with social engineering, this kind of mainline metering should be instituted only with the approval of the local metropolitan planning organization (MPO) to encourage growth in the desired locations. WSDOT policy encourages coordination of these types of public policy decisions with the local MPO.

In either use of mainline metering—improving bottleneck flow and system efficiency or encouraging certain trip and land use patterns—politics plays a large role. In fact, political opposition may well be the largest obstacle to employing mainline metering. Most current sentiments are that mainline metering is too controversial and that highways should not be obstructed by meters. A rigorous and extended educational campaign would most likely be necessary to make the potential benefits known to those in decision-making positions and to convince them that mainline metering is a workable traffic management strategy.

Operational Issues

One of the critical components of the successful operation of a mainline metering system is the safety of the traveling public. Fortunately, there are numerous examples of toll plaza operations that function almost identically to mainline metering. In fact, the signing for mainline metering would be similar to that required for mainline toll booths. Mainline toll booths are common in other parts of the country and have been installed in Washington State before. Some of these traditional toll facilities often operate as unintentional mainline meters. This is especially true when the number of toll booths is insufficient for the traffic flow, creating traffic queues.

Because traffic queues are possible at a mainline metering installation, the ideal location for mainline metering is at the end of long, straight stretches of freeway where approaching drivers would have a good view of the queue's end. It also would be possible to have signs actuated by queue loop detectors that could warn of extended queues. A variable message–speed limit sign at the southbound entrance to the Golden Gate Bridge warns approaching drivers of the traffic conditions ahead at the toll plaza. This arrangement could be emulated for mainline metering.

To encourage increased bus ridership and the formation of carpools and vanpools, an HOV lane should be built to allow HOVs to bypass the mainline metering traffic queue. The HOV lane should extend from the mainline metering upstream to the rear of the worst anticipated traffic queue.

Metering of the HOV lane should also be considered. Some areas of California meter the on-ramp HOV lanes at the same location as the general-purpose lanes. Metering is an excellent tool for making enforcement of the HOV lane efficient and safe. Other areas of California do not meter the HOV lanes. In Washington State there is one metered HOV lane (the northbound on ramp to the I-5 express lanes at Pike Street in Seattle), which operates in conjunction with the Metro bus tunnel on ramp to the express lanes.

Some of the issues related to mainline metering concern drivers' expectations. Most drivers do not expect a traffic light on a freeway; therefore, mainline metering would require some adjustment time and probably some educational marketing strategies. Presumably, mainline metering would operate in coordination with and during the same hours as ramp metering; the metering would be turned off the rest of the time.

SUGGESTED POLICIES AND GUIDELINES FOR WASHINGTON STATE

The operational success of a number of freeway-to-freeway ramp metering systems currently installed around the country and the successful installation of a mainline metering system in San Francisco, California, have been discussed. The lessons learned from these real-life examples are invaluable and have been heavily drawn on in the development of suggested policies and guidelines for the installation and operation of freeway-to-freeway ramp metering and mainline metering in Washington State. However, a complete and thorough analysis should take place before the installation of any freeway-to-freeway or mainline metering system in Washington State. This analysis is needed to ensure that safety is maintained and that environmental concerns are addressed. In addition, in the majority of cases, the traffic impacts of these types of metering systems should be evaluated on a regional level and should be incorporated as part of an overall, areawide congestion management plan.

Freeway-to-Freeway Ramp Metering

The suggested policy on freeway-to-freeway ramp metering is to install meters on freeway-to-freeway ramps where system performance and efficiency will be improved.

Suggested guidelines for freeway-to-freeway ramp metering include the following.

- Consider and implement freeway-to-freeway ramp metering where recurring congestion is a problem or where route diversion should be encouraged. Installation of the meters should be accompanied by a marketing and publicity campaign.
- Consider route diversion only where suitable alternative routes exist to avoid diverting drivers through residential neighborhoods. Normally, route diversion is not the intention of freeway-to-freeway ramp metering. Instead, freeway-to-freeway ramp metering should be installed to improve the mainline flow and on-ramp merge or to help multiple ramps merge into one ramp. If the intent of the metering is route diversion, then consider trailblazers or appropriate signing to educate drivers on preferred alternative routes.
- Avoid metering vehicles twice within a short distance. If ramp meters are installed within 5 km (3 mi) upstream of a freeway-to-freeway ramp, the freeway-to-freeway ramp should not be metered.
- Avoid metering single-lane, freeway-to-freeway ramps that feed traffic into an add lane. Because the maximum single-lane metering rate is usually 900 vph (although it can be increased by allowing two vehicles per green cycle), an add lane with a capacity of over 2,000 vph would be underutilized.
- Do not install meters on a freeway-to-freeway ramp unless analysis ensures that the mainline flow will be improved, so that people using the freeway-to-freeway ramp are rewarded for waiting in line at a metering installation.
- Install meters on freeway-to-freeway ramps where two or more ramps merge before feeding onto the mainline and congestion on the ramps occurs regularly (four or more times a week during the peak period).
- If traffic queues that impede mainline traffic develop on the upstream mainline because of freeway-to-freeway ramp metering, increase the metering rate to minimize the queues on the upstream mainline or provide additional storage capacity.
- Monitor and control freeway-to-freeway ramp meters by the appropriate traffic management center.
- Whenever possible, install meters on roadways that are level or have a slight downgrade, so heavy vehicles can easily accelerate. Also, install meters where the sight distance is adequate for drivers approaching the metering to see the queue in time to safely stop.

Mainline Metering

The suggested policy on mainline metering is to install mainline meters on freeways approaching bottleneck locations where analysis indicates that improved traffic operations will result.

Suggested guidelines for mainline metering systems include the following.

- Whenever possible, install meters on roadways that are level or have a slight downgrade, so heavy vehicles can easily accelerate.

- Install meters where the sight distance is adequate for drivers approaching the mainline metering to see the queue in time to safely stop.
- Provide an HOV lane that allows HOVs to bypass the mainline metering traffic queue. The HOV lane should extend from the mainline metering upstream to the rear of the worst anticipated traffic queue.
- Perform an extensive marketing and publicity campaign before installation of mainline metering in Washington State.

ACKNOWLEDGMENTS

The authors appreciate the following individuals and institutions for their help in compiling this document: from Caltrans, Larry Lowden (Los Angeles), Milton Ikeda (Los Angeles), Doug Richter (Los Angeles), Max Wickham (San Diego), and Jim McCrank (San Francisco); from MnDOT, Glen Carlson (Minneapolis); from FHWA Jeff Lindley (San Francisco); from University of Washington-Transportation Center, Amy O'Brien, Michael Meulemans, Duane Wright, Ron Porter, and Eva Nachmanson; and from Parsons Brinckerhoff, Melissa Laube (Boston).

REFERENCES

1. Haboian, K. A. *Freeway Management Strategies.* Parsons Brinckerhoff Monograph 8. Parsons Brinckerhoff, Inc., New York, July 1993.
2. MacCalden, M. S., Jr., A Traffic Management System for the San Francisco–Oakland Bay Bridge. *ITE Journal,* May 1984, pp. 46–50.

Publication of this paper sponsored by Committee on Freeway Operations.