Interstate 80 Integrated Corridor Mobility Project

Ramp Metering Plan
Revised Final

By

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1 PURPOSE OF DOCUMENT

This document is prepared in conjunction with the analysis of alternatives of the I-80 Integrated Corridor Mobility (ICM) project. The objectives of this document are threefold:

- To provide background information on ramp metering that will improve stakeholder understanding of ramp metering as a traffic operations strategy;
- To present the proposed application of ramp metering with the I-80 corridor with respect to the geometric limits, geometric design, and operational strategy; and
- To summarize an initial assessment of ramp metering within the I-80 corridor based on existing and forecasted demands, operational analysis results, and the physical characteristics of the individual ramps.

With regard to the third objective, it is important to understand that the results of this initial assessment are based largely on forecasted conditions. Actual impacts are, of course, dependent upon the actual demands experienced at a given time. Furthermore, it is fully expected that any ramp metering system would be fine-tuned in the field and have the adaptive capability to respond to changing conditions. Thus, this assessment is intended to provide an understanding of the potential benefits and impacts, and highlight locations where ramp improvements may be appropriate.

2 SCOPE OF THE PROJECT

2.1 The Problem

The Interstate 80 (I-80) corridor has ranked as the most congested corridor in the entire San Francisco Bay Area during the last six years, with traffic volumes reaching 312,000 vehicles per day and an average of 20,000 hours of delay daily. Currently, the demand on the freeway exceeds the roadway capacity, causing unreliable travel times, erratic operating speeds, breakdowns, as well as diversion to the local arterials. The congestion on the roadway network contributes to an increase in incident rates, including rear-end accidents on both freeway and local arterials. These contribute to delays for transit services operating along the corridors. The combined effect of the incidents and the congestion hinders efficient response times and creates additional secondary incidents.

A summary of existing future year conditions is provided in the following sections. A more detailed discussion of these conditions is presented in other I-80 ICm Project documents including the *I-80 ICM Project Traffic Operations Analysis Report* and the *I-80 ICM Project CSMP Comprehensive Performance Evaluation Report*.

2.1.1 Existing Facility

Interstate 80 is a major east-west freeway connecting San Francisco to Solano County (and beyond), passing through Alameda County and Contra Costa County. In general, Interstate 80 has three mixed-flow lanes between the Carquinez Bridge and Interstate 580 (Albany), and there are five mixed-flow lanes between Interstate 580 (Albany) and Powell Street (Emeryville). For some segments, an auxiliary lane has been installed on the mainline between an on-ramp and the off-ramp immediately downstream. There is also a High-Occupancy Vehicle (HOV) lane between Highway 4 and San Francisco Bay Bridge toll plaza.

There are approximately 50 on-ramps along the project corridor that provide access from local arterial roadways onto Interstate 80, including HOV-only center median on-ramps at Richmond Parkway (Pinole) and Cutting Boulevard (Richmond). Most of the on-ramps are diamond configuration that allow access to the freeway from both directions of the cross street. There are also several locations where loop ramps are utilized to serve only one direction of cross street traffic (e.g., eastbound Cutting Boulevard on-ramp to eastbound Interstate 80). In addition, most of the on-ramp locations feature significant slope considerations as they join the freeway.

2.1.2 Existing Operating Conditions

The operating conditions of the freeway in existing conditions, 2008 are listed below with level Of Service (LOS) that represents the thresholds defined in the Highway Capacity Manual (HCM).

- During the AM peak,
  - There is no significant congestion in the eastbound direction. LOS B to D is observed in most segments.
  - There is significant congestion in the westbound direction. Congested conditions begin to appear around 7:00 AM and dissipation occurs between 9:00 AM and 10:00 AM. LOS ranges from a 'C' east of Highway 4 to a 'D' east of the Richmond Parkway to an 'E'/'F' from San Pablo to the Bay Bridge Toll Plaza.
- During the PM peak,
  - The congestion is more pronounced in the eastbound direction compared to that during the AM peak hour. Congestion starts at approximately 3:30 PM between Powell Street and Buchanan Street and progresses towards Highway 4 by 6:00 PM. LOS ranges from a 'C'/'D' between I-580 and San Pablo, and again between Highway 4 and Crockett, and an 'E'/'F' throughout the rest of the corridor.
  - There is less congestion in the westbound direction than during the AM peak hour. Congestion is typically limited to the segment west of the I-580 junction (between Buchanan Street and Powell Street) beginning around 3:15 PM and remains that way until the end of the afternoon peak period. Most segments have LOS C.

2.1.3 Future Facility

It is assumed that the future facility will represent all the planned and programmed capital improvements along the I-80 study corridor. The relevant improvement projects are summarized in **Table 2-1.** Most of these projects consist of interchange modifications, the extension of the HOV lanes from SR 4 to the Carquinez Bridge is also proposed.

Table 2-1 I-80 Corridor Planned Capital Improvements

Project Name	Source
I-80 Gilman Interchange Reconfiguration	MTC '05-'06 5-year TIP
I-80/Central Ave Interchange Modification	MTC '05-'06 5-year TIP
I-80: Extend Eastbound HOV Lane – SR 4 to Carquinez Bridge	MTC '05-'06 5-year TIP
I-80/SR 4 Interchange: WB 80 to EB 4 Direct Connectors1	Contra Costa County '05 7-year CIP
I-80/SR 4 Interchange: Remaining Components[1]	Contra Costa County '05 7-year CIP
I-80/San Pablo Dam Road Interchange: Reconstruct	Contra Costa County '05 7-year CIP
I-80: Install Ramp Metering Hardware Bay Bridge to Carquinez Bridge	Contra Costa County '05 7-year CIP
SR 4 West: Phase 2 (Full Freeway) I-80 to Cummings Skyway[1]	Contra Costa County '05 7-year CIP
Widen Cummings Skyway Interchange at I-80[1]	Contra Costa County '05 7-year CIP

It should be noted that a number of the capital projects listed in **Table 2-1** are of uncertain status with respect to funding.

2.1.4 Future Operating Conditions

For 2015, traffic demand on I-80 in the westbound direction is projected to increase by up to 10%. In the eastbound direction, traffic demands during the AM peak hours are projected to increase in the range of 14% to 20%. During the PM peak hours, eastbound traffic demand is projected to grow by approximately 5% within the segment from the Bay Bridge to Hilltop Dr. East of hilltop Drive, demand is expected to increase by 5% to 10%. Westbound, demand is expected to increase between 5% and 15%.

In 2035, the I-80 westbound traffic demands during the AM peak hour are projected to increase by 54% to 60% between “South of SR- 4” and “Carquinez Bridge”. In the western portion of the corridor, where there is congestion in existing conditions, the peak hour growth rates are projected in the range of 30% to 45%. During the PM peak, the I-80 eastbound traffic demands are projected to increase by 25% to 40% along the entire freeway, from the Bay Bridge to the Carquinez Bridge.

[1] Per the City of Hercules, alternatives to these projects are currently being studied and may lead to revisions to the CIP and TIP/RTIP lists, Furthermore, a major intermodal facility, integrated into the freeway system, is being proposed for this area. The City has suggested that these alternative improvements and transit-oriented development be incorporated into any subsequent analysis of future year conditions at the I-80/SR 4 Interchange.

In both 2015 and 2035 conditions, the highest growth was predicted for those segments of I-80 where there is little or no congestion currently. However, even with the moderate growth forecasted for the currently congested segments, the forecasted growth is high enough to worsen the LOS of some freeway segments. It is expected that both the geographic limits and duration of congestion on I-80 will expand during both peak periods. The forecasted 2015 and 2035 conditions are further discussed below.

2015 Operating Conditions

Westbound: the operating condition on the general purposed lane would be worse than the existing condition especially at the west end of the corridor. The segments currently operating at LOS B or C would operate at LOS F under year 2015.

With the projected increase in the traffic demands, relative to Existing Conditions, it can be seen that:

- During the AM peak hour,
  - The forecasted freeway LOS in the eastbound direction under the 2015 conditions is projected to degrade slightly, but both the general purpose and HOV lanes are expected to operate at acceptable LOS. No severe congestion is expected.
  - Congestion will worsen resulting in longer queue and more bottlenecks. LOS E/F conditions are expected to extend from the Bay bridge to approximately SR 4.
- During the PM peak hour,
  - Congestion in the eastbound direction is expected to worsen, with many segments dropping from LOS D or better to LOS E and F. It is, however, expected that the HOV lane would still operate at good service level.
  - Congestion in the segment west of the I-580 junction (between Buchanan Street and Powell Street) is expected to worsen with additional segments operating at LOS E/F.

2035 Operating Conditions

With the projected increase in the traffic demands, relative to Existing Conditions, it can be seen that:

- During the AM peak hour,
  - The forecasted freeway LOS in the eastbound direction under the 2035 conditions is projected to be worse than the existing freeway LOS (LOS B to LOS D in 2008 changed to LOS C to LOS E in 2035). No severe congestion is expected.
  - Severe congestion is expected along the entire length of the westbound direction.
- During the PM peak hour,
  - More congestion in the eastbound direction is expected compared to the AM peak hour. LOS D to LOS F is expected along most segments.
  - Less congestion in the westbound direction is projected during the AM peak hour. Most segments are expected to operate at LOS C to LOS D.

2.2 I-80 Integrated Corridor Mobility (ICM) Project

The primary goal of the I-80 ICM Project is to enhance the current Transportation Management System along the I-80 corridor to build a balanced, responsive, and equitable integrated system to monitor and maintain optimum traffic flow along the network to improve the safety and mobility for all users, including transit customers. This project uses State-of-the-Practice Intelligent Transportation System (ITS) technologies to enhance the effectiveness of the existing transportation network in both freeway and parallel arterials in Alameda and Contra Costa Counties. The project will create a balanced network with an emphasis on system reliability and efficiency through multi-modal solutions. Proposed project sub-systems include:

- Freeway Management System
- Corridor-wide adaptive ramp metering (ARM) including ramp metering bypass lanes for transit access
- Speed harmonization through enforceable variable speed limit (VSL) signs
- Arterial Management System
- Transit Management System
- Traveler Information System
- Commercial Vehicle Operations (CVO)
- Traffic Surveillance and Monitoring System
- Incident Management System

The project also includes integration with the East Bay SMART Corridors Program (a joint Alameda and Contra Costa County ITS program) and the Caltrans Transportation Management Center (TMC). The I-80 ICM project consists of multiple systems and strategies, working collectively, to address the challenges of imbalanced traffic flow in the corridor. Since this corridor is constrained on both sides (by water and mountains), the most feasible congestion management alternative is to improve the efficiency of the total transportation system.

The strategies proposed to improve the corridor represent a multi-pronged approach to managing the different challenges along the corridor. The system components of the I-80 ICM project are listed in **Table 2-2.**

Table 2-2 I-80 ICM Project System Components

System Component	Element	Purpose
Freeway Management System	Adaptive Ramp Metering Enforceable Variable Speed Limit Signs Changeable Message Signs Lane Use Signs	Speed harmonization, optimize flow of traffic, reduce delay, decrease incidents, merge control, decrease arterial spillover, and improve safety
Transit Management System	Ramp meters with HOV bypass for transit access only Transit Signal Priority Transit/traffic traveler information at BART stations	Improve travel time reliability, reduce travel time, encourage mode shift
Arterial Management System	Coordinated traffic signal systems, TMC for local jurisdictions	Optimize traffic flow on arterials, maximize coordination
Incident Management System	Vehicle detection system, incident response plan, diversion management	Decrease number of incidents, decrease incident response time, and decrease incident recovery time
Traveler Information System	511 enhancement, SMART Corridor ATIS enhancement, Changeable Message Signs , Highway Advisory Radio	Enhanced traveler information for all users Minimize diversion during incident
Traffic Surveillance and Monitoring System	CCTV cameras, vehicle detection system	Traffic Monitoring to support other systems
Commercial Vehicle Operations	Future preferential treatment of CVO, value pricing	Best time use of freeway by commercial vehicle users

2.1 Project Limits

The project covers the freeway and important arterials in the I-80 corridor between the Carquinez Bridge (Contra Costa County) and San Francisco Bay Bridge Toll Plaza (Alameda County). The limits of this project encompass locations in both Contra Costa County and Alameda County as shown in **Figure 2–1.**

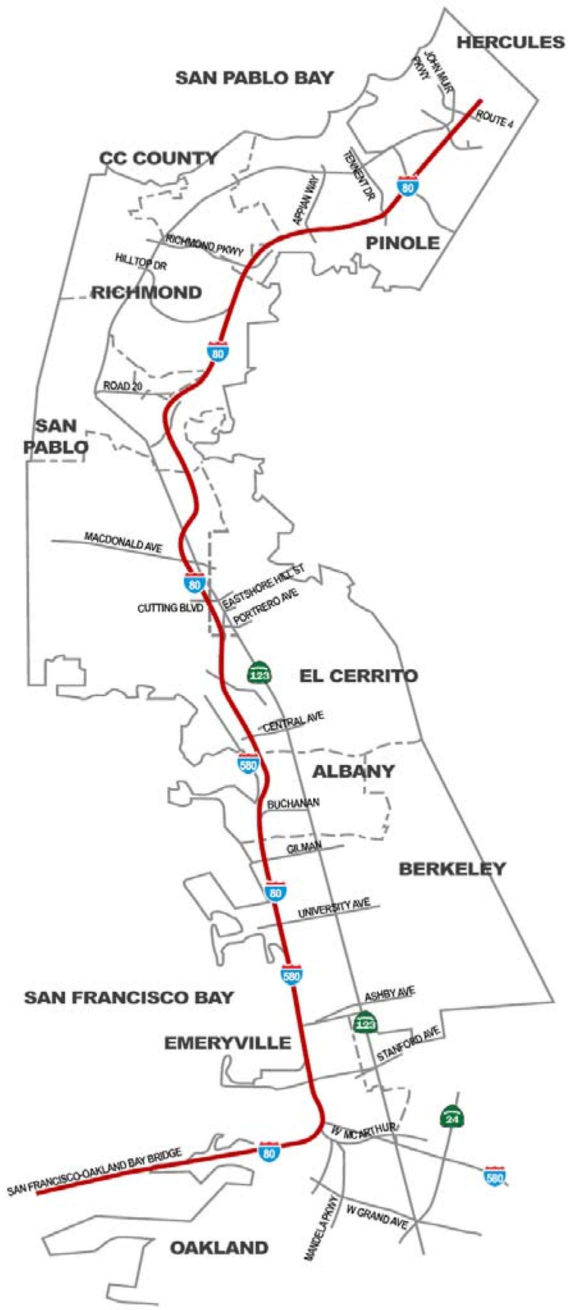

Figure 2–1 I-80 ICM Project Area

3 RAMP METERING OVERVIEW

Ramp metering is a traffic operations strategy whereby traffic entering a freeway is controlled with a traffic signal. At its simplest level, this is done to limit the volume on the mainline, thereby eliminating or reducing congestion. The most common type of ramp metering is on-ramp metering, where a traffic signal is placed on a ramp from an arterial (surface) street, and traffic is only permitted to enter the freeway at set intervals (typically one vehicle every few seconds). Meters can also be used on freeway-to-freeway connectors, and even on the freeway mainline (generally at bridges or tunnels). Ramp meters can be designed to control all traffic, or allow HOV (high occupancy vehicles, or carpools) to bypass the meter.

Ramp meters were first installed in 1963 as part of the Chicago Area Expressway Surveillance project on the Eisenhower Expressway. In California, metering was first introduced in Los Angeles in 1968. The first ramp metering systems were limited to simple pre-timed systems based on historical data. In 1978, a ten-mile section of Routes 94 and 125 in San Diego County became the first California freeways to be controlled as a system of ramp meters with traffic responsive control. Subsequent improvements in computers, vehicle detectors, and communications technology have resulted in even more sophisticated systems. Ramp metering systems can be coordinated for multiple ramps, consider historical and current traffic data, and even integrate freeway and arterial control systems.

While metering is not right for every situation, proof of its usefulness can be found in its growth rate. Between 1989 and 1995, the number of ramp meters in the United States increased 45 percent. Today, ramp metering is used in a total of 23 metropolitan areas in the U.S., and there are almost 1600 meters in California. Another 1400 ramp meters are either programmed or planned in the state. Metering is also being used in England, France, and the Netherlands.

In the Bay Area, ramp meters are most common in the South Bay, especially Santa Clara County where metered freeways include SR 17, SR 85, SR 87, US 101, SR 237, I-280, and I-880. Caltrans has also installed meters on I-880 and I-580 in Alameda County, and on US 101 in San Mateo County. There a few non-operational meters on SR 4 and SR 242 in Contra Costa County, and on US 101 in Solano County. Freeway-to-freeway metering has been tried on SR 85 and its connections to I-280 and SR 87. The most well known metering occurs at the San Francisco Bay Bridge, where the “metering lights” just past the toll plaza control the traffic using the westbound lanes of I-80.

3.1 Potential Benefits and Impacts

The basic concept behind ramp metering is relatively simple: when freeways are congested because demand exceeds capacity, ramp meters can be used to manage traffic. Demand can be redistributed over time, space, and/or mode:

- Time Distribution - This occurs when vehicles are stored on ramps and released later, or encouraged to start their trips at different times. Also, metering that causes on-ramp queues effectively transfers excess demand (and delays) from mainline freeway bottlenecks to on-ramps. From a system perspective, this may be a more efficient distribution of congestion. Even better, some delay may actually be eliminated from those vehicles who exit the freeway before a bottleneck but were previously delayed from a long queue on the freeway.

- Space Distribution - This occurs when vehicles divert to other routes, either by selecting a different on-ramp or avoiding the freeway altogether. By eliminating (or reducing) freeway bottlenecks, ramp metering can increase the total vehicle-miles of travel served by the freeway as longer freeway trips are encouraged. This will reduce the total travel on the rest of the network, although surface street traffic may increase in localized areas.
- Mode Distribution - This occurs when travelers are encouraged to switch to transit or carpools because of the time savings of these modes when HOV bypasses are available.

Since ramp metering was first implemented, there have been many ramp metering success stories, but it is also clear that ramp metering is not a panacea for all freeway operational problems. Proponents of ramp metering paint a picture of a computer-controlled system that improves freeway operations to free-flow speeds without degrading the performance of the arterial street system. At freeway on-ramps, motorists will have a short wait at the ramp meter signal, but more than make up for their delays with much faster freeway trips. If implemented correctly, it will be accepted by the general public and transportation operating agencies as a strategy that equitably improves the regional transportation system for all users.

At the other extreme, some planners, public officials, and citizens envision the worst when a ramp metering system is proposed for their area. They believe that ramp metering can improve freeway speeds, but recurring freeway congestion may still occur. Frustrated motorists will be forced to wait for several minutes at the entrance to a freeway that is supposed to be “free”, and will make up little time once they are on the freeway. Even worse, ramp queues will back up to surface streets and cause gridlock at nearby signalized intersections, and motorists will divert from the freeway to increase traffic on already congested local streets. The only benefits will be enjoyed by motorists making long trips through the metered area, and these drivers may not even have to wait at a meter, increasing incentives for exurban growth and exacerbating the congestion problem.

In practice, most ramp metering systems fall somewhere in between these two extremes. When applied correctly and in the right circumstances, ramp metering can be a highly effective tool for improving freeway operations, but it can cause some of the problems described above. The key to understanding the benefits and impacts of a ramp metering system is to consider the options for a new system, analyze the merits of various plans, and make an informed choice that is right for a particular set of circumstances. This systems approach to analyzing ramp metering is a logical process that can be tailored to each area.

Some types of freeway congestion may be more appropriate for ramp metering control than others. The classic problem is a recurring breakdown at a bottleneck location downstream of a set of moderate-volume ramps from bedroom communities. Ramp metering may be less effective when a large proportion of freeway traffic comes from high volume ramps, especially if they are freeway connectors that cannot be metered. The problem becomes more complex when there are multiple, or hidden bottlenecks, especially if demand is very much in excess of capacity. Ramp metering can be effective for reducing the length or intensity of freeway congestion, especially around the shoulders of the peak periods.

Ramp metering can have a host of impacts to the regional transportation system, both positive and negative. **Table 3-1** lists these impacts, which are discussed further in the remainder of this section.

Table 3-1 Summary of Ramp Metering Impacts

Potential Positive Benefits	Potential Negative Impacts
Maintain mainline freeway flows and speeds -– avoid "two capacity" phenomenon	Diverting vehicles degrade arterial performance
Reduce variance of travel times	Queue spillbacks affect nearby intersections
Smooth entry onto freeways; improve safety	
Provide local authorities with greater control over freeway and arterial traffic assignment/diversion	SOV use is encouraged for long trips
Balance flow during incidents	Inequitable changes in travel time
Discourage short freeway trips	
Provide HOV/transit incentives	Encourage urban fringe growth

Source: DKS Associates

The primary objective and benefit of ramp metering is to maintain freeway flows and speeds by controlling the entry of vehicles onto the freeway. At its simplest level, this is done to limit the volume on the mainline, thereby eliminating or reducing congestion.

Related to the above, ramp metering may be useful in preventing what has been called the "two capacity" phenomenon. Some researchers have suggested that there is a subtle difference in the maximum attainable flow rate on a freeway: this rate (the capacity) is higher before congestion occurs at a bottleneck. Once a queue occurs, the maximum flow rate is lower. Therefore, ramp metering can theoretically be used not only to prevent breakdowns but actually increase freeway capacity. Increases in flow rates of up to ten percent have been reported. In practice, it is difficult to meter traffic to attain this maximum flow rate without causing a breakdown.

Furthermore, some researchers have suggested that ramp metering reduces the variance of trip times. By controlling freeway congestion and creating limited, controlled queues on ramps, drivers' travel times may become more consistent on a day-to-day basis.

Another effect of ramp metering is to break up platoons of vehicles arriving from nearby signalized intersections. This may reduce turbulence in the merge area on the freeway, thereby eliminating a bottleneck. Spreading a thirty second burst of vehicles over a full minute may result in only very short delays on the ramp while greatly increasing freeway speeds. It may also reduce traffic accidents in merge areas.

Another potential benefit of ramp metering, which is often overlooked, is its use for incident management. Most freeways suffer a significant capacity reducing incident every two or three days, so metering for "unusual" traffic conditions may actually be typical. When an incident occurs, ramp meters can be used to reduce the volume of vehicles upstream of the congestion, and increase the rates (for metered ramps) downstream. Safety can be a related benefit: as drivers experience less freeway congestion, fewer crashes may occur.

Ramp metering is also a very effective tool that enables Caltrans and local agencies to have more control over freeway and arterial traffic assignment and diversion. Caltrans in partnership with local authorities can reduce or increase the metering rates at an on-ramp to discourage or encourage the commuters to use the subject on-ramp.

Ramp metering may be most effective when a good alternate route is available. When metering is introduced, some trips will be diverted to local streets. (The magnitude of diversion depends on the roadway network, ramp metering rates, and levels of congestion). The availability of a direct, relatively uncongested parallel arterial route will encourage drivers using the freeway for short trips to use the surface street system instead. In fact, this is sometimes a goal for a ramp metering system.

While many arterial systems could handle a small increase in traffic volumes from diverted vehicles, surface streets near congested freeways may already be congested from drivers who use major arterials as a freeway alternate. Typically, the volume of traffic that diverts from freeway on-ramps is relatively low, but it may be enough to reduce the level of service on a marginally functional arterial system. Even if overall diversionary effects are relatively minor, specific movements at specific intersections can still be negatively impacted due to changed travel patterns.

Conversely, by improving mainline performance, ramp metering can encourage drivers to use or stay on the freeway. In practice, when a section of freeway becomes congested, some drivers will try to bypass the freeway congestion by using the arterial streets and entering the freeway at/or downstream of the bottleneck. For long-trip users, this may mean exiting the freeway congestion and using the arterials to go to downstream on-ramps and re-enter the freeway. The local (local resident) freeway user, rather than using the nearest on-ramp to their origin to access the freeway, may use the downstream on-ramps to bypass the freeway congestion. When the freeway on-ramps are metered, the above-mentioned Long Trip Freeway User is not likely to exit the freeway, because freeway is less congested and if they exit to use the downstream on-ramps they will be delayed at the metered on-ramp. Also, with metering, local residents are more likely to use the nearest on-ramp to their origins (because freeway is flowing better) rather than using local streets to access downstream on-ramps.

Another obvious potential impact occurs when ramp queues spill back to surface streets and block nearby signalized intersections. Spillback detectors can prevent this from occurring, but short storage lengths on many urban freeway ramps preclude effective operations without some queue spillback.

In addition to local intersection operational impacts, ramp metering can unevenly impact the travel times of motorists in different areas. For example, those who make longer trips through the metered area may have greater travel time benefits than those with shorter trips, and some travelers may actually incur longer travel times. Ramp metering also may have the effect of replacing short freeway trips with longer ones, thus indirectly benefiting certain motorists. Besides the political equity issues that this may raise, the benefits to long-distance commuters may encourage growth in urban fringe areas, which can compound the congestion problem. In some cases, the metering of freeway-to-freeway connectors can help mitigate these impacts.

Ramp metering may have a mixed impact on mode choice. With a good enough system, some travelers might switch from carpools or transit to single occupancy vehicles (SOVs), which would increase freeway congestion. If HOV bypass lanes are provided, however, SOV drivers might be encouraged to switch to other modes of transit to take advantage of the travel time savings. Realistically, the overall regional impact would likely be small, but could significantly affect mode choice in local areas (e.g., near metered ramps).

3.2 Ramp Metering Design and Operating Parameters

There are many different types of ramp metering, but the typical design of a ramp meter is illustrated in **Figure 3–1**. Vehicles entering the freeway at the on-ramp are required to wait for the signal at the stop bar on the ramp before proceeding onto the freeway. Ramp meter signals can either be two-head (with green and red signal heads) or standard three-head signals. Either way, the green signal is left on for a short time (1.5 seconds is enough for a single vehicle), and then changes to red for several seconds. The cycle length is the total time (e.g., 6 seconds) it takes to go through one green-red cycle. The metering rate (e.g., 600 vehicles/hour) is the number of vehicles allowed to pass through the meter in one hour. A more restrictive rate (a lower number) will reduce the number of vehicles on the freeway, potentially improving freeway operations, but possibly causing excessively long queues or diversion.

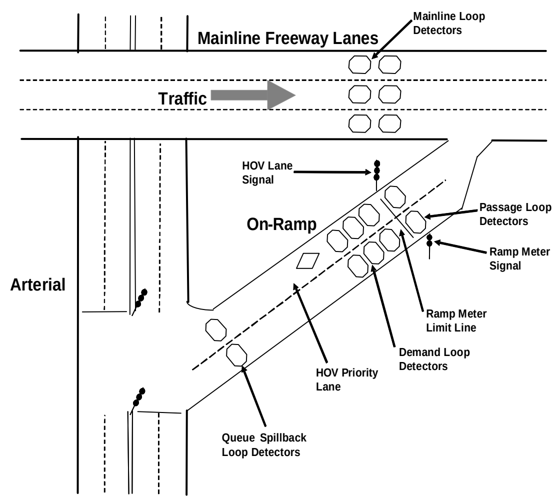

Figure 3–1 Typical Ramp Metering Design

The on-ramp can have one or more lanes; vehicle discharges on multi-lane ramps can be staggered if necessary. Also, one lane can be used as an HOV priority lane, where carpool and transit vehicles are not required to wait for the ramp meter signal, or metering rates are higher to reduce queues for HOVs. A very high volume ramp might have two mixed-flow lanes and one HOV lane. Similar ramp meters can also be used on freeway connectors, where it may be necessary to meter two or more lanes.

The figure illustrates how a system of traffic loop detectors, embedded in the roadway, can be used to operate the ramp meter. The mainline detectors (labeled as A) are used to monitor traffic on the mainline freeway and can be used to set metering rates. The passage (sometimes called check-out) detectors (B) are used to indicate when the ramp meter signal should be reset to red, and to monitor violations. The demand (sometimes called a check-in) detector (C) is used to start the ramp meter signal cycle. Finally, the queue detector (D) is used to prevent spillback to the arterial. When the occupancy levels on this detector reach a certain threshold (indicating a queue), the metering rates can be increased. Note that the detector arrangement pictured here is typical, but many other variations are used.

The remainder of this section identifies the key attributes or parameters that are useful for defining a specific ramp metering system. These parameters are: geographic limits, time period, queue limits, HOV treatment, metering control strategy, metering rates, and ramp geometrics.

3.2.1 Geographic Limits

The first parameter to consider in defining a ramp metering system is the extent of ramp metering coverage. This may be pre-defined by geographic or jurisdictional boundaries, but in many cases there are opportunities to change limits. At a minimum, ramp metering should include all current and anticipated congested freeway segments. It may be difficult to develop an effective ramp metering plan if only a few ramps can be metered; the volumes at metered on-ramps should constituent a large percentage of traffic on the freeway. It is often necessary to extend ramp metering limits beyond congested areas so that drivers in one jurisdiction are not forced to endure long queues.

A second element of this parameter is identifying which ramps will be metered. Typically all local interchange on-ramps within the designated limits are metered. Freeway to freeway connector metering is less common, but can be particularly useful for ramp metering, because connectors tend to have high traffic volumes. A critical issue for connector metering is to determine if queues from meters might affect freeway operations on the feeder freeway. Mainline metering is relatively rare, but can be appropriate in certain circumstances.

3.2.2 Time Period

Because ramp metering is generally viewed as a congestion management strategy, it is typically applied only when congestion does or is expected to occur. An understanding of corridor conditions is necessary to define when the meters may be turned on and off. More advanced systems that include the capability to monitor freeway conditions can be set up to automatically turn on or turn off the meters as conditions warrant. Beyond the typical peak periods, ramp metering may be useful to support special event and incident management activities. In short, ramp meters are most effective, and most accepted, if they operate when conditions warrant.

3.2.3 Queue Limits

Many ramp metering systems use spillback detectors to prevent queues from reaching arterials, so queue limits are constrained by the length of the on-ramps in the system. One common problem that is reported for new ramp metering installations is that ramp queue lengths are too short, and override (queue) detectors contradict the intent and limit the effectiveness of ramp metering.

In specifying queue limit parameters for ramp metering design, some options are available for adding to queue limits. First, ramp geometries should be examined to see where queues could extend back to surface streets without affecting arterial signal operations. Signal timing and phasing can be adjusted to allow queues to form in turn lanes that do not affect other arterial traffic.

3.2.4 HOV Treatment

HOV priority lanes which allow HOVs and transit vehicles to receive preference at the ramp meter can be an effective way to reduce person travel times. Since HOVs are avoiding ramp delays and benefiting from reduced freeway travel times, more people have shorter trip times. This has the added benefit of encouraging mode shifts away from SOVs. However, SOVs will then be forced to wait longer at ramp meters, and may illegally use the HOV preferential lanes. This can increase frustration for honest drivers and reduce the effectiveness of the ramp metering system. Therefore, enforcement is a critical element of an HOV preferential lane implementation.

3.2.5 Control Strategy and Metering Rates

There are many types of control strategies that can be used with ramp metering; these are often referred to as algorithms. These can vary from simple, fixed-timed strategies where metering rates are preset, to adaptive algorithms where metering rates may vary in accordance with prevailing conditions. In turn, these adaptive algorithms can vary greatly in their level of sophistication from those where each ramp meter operates individually and rates are set according to freeway conditions within the immediate vicinity, to those where meter operation is coordinated and metering rates are based on the performance of the entire corridor. These different control strategies or algorithms are discussed further in Section 3.3.

Within any of these control strategies, metering rates can vary by location and by time period, and should be set according to actual conditions and constraints. However, there is a practical minimum and maximum metering rate that can be used on each ramp. This becomes a key issue for low- and high-volume ramps. For low volume ramps, it may not be possible to meter traffic so that the on-ramp throughput is reduced during the metering period. The issue is even more critical for high-volume ramps, which obviously contribute more to freeway congestion. For these ramps, it may be difficult to set a metering rate that is high enough so that extensive queues do not form. If this is the case, metering may not be used on a particular high-volume ramp, causing two problems. First, other, lower-volume ramps may need to be metering more heavily to make up the difference. Then, vehicles may divert and use the unmetered ramp(s), exacerbating the problem. One solution to this problem is to add lanes to high-volume ramps, which increases the range of usable metering rates and also provides more storage.

For single lane ramp metering, the maximum rate typically used is 900 vehicles per hour (vph), using a 2.5 second red phase and a 1.5 second green phase. The minimum rate used is 240 vph, based on a 13.5 second red phase and a 1.5 second green phase. (It has been found that drivers start ignoring the red ramp meter signal once the total cycle length exceeds 15 seconds.) In the Bay Area, Caltrans typically uses minimum and maximum rates of 240 and 900 vph, although a minimum rate of 180 vph has been used in some cases.

Platoon metering can be used to increase the maximum rate. With this system, two or more cars per lane are released every green cycle. Two car platoon metering (using a 2.5 second red phase and a 3 second green phase) can theoretically yield about 1300 vph., but 1050 vph is a more practical limit. Platoon metering is not commonly used in California (there are a few locations in the South Bay), but has been employed in Texas. It is a common practice in England, where multiple-car platoons are sometimes used.

3.2.6 Ramp Geometrics

On-ramp geometry can have a significant influence on ramp metering effectiveness and impacts. The number of lanes determines the maximum metering capacity and whether HOV priority lanes may be provided. The length and grade of a ramp are also important as they help determine the placement of the ramp meter stop bar and the amount of storage.

With multiple-lane ramps, the maximum ramp metering rate can be extended. With a two-lane on-ramp, vehicles can be released from alternate lanes every two seconds (i.e., using a four second cycle for each lane), providing a theoretical maximum rate of 1800 vph (in practice, rates higher than 1600 vph are rarely achieved). Obviously, this is only feasible on ramps with more than one lane, but a key consideration in ramp metering design is to identify ramps that can be widened.

Adding lanes to on-ramps to provide more storage may also be a cost-effective way of improving freeway operations. Placement of the ramp meter stop bar also affects storage, although there should be at least 300 to 600 feet of acceleration distance between the stop bar and merge area on the freeway. The distance between the ramp meter stop bar the merge point depends on the grade of the ramp and the traffic composition (especially trucks).

3.3 Ramp Metering Control Strategies

As previously noted, there are many types of control strategies or algorithms that can be used with ramp metering. With the exception of the fixed-timed strategy, the remaining four may be viewed as adaptive algorithms in that ramp metering rates change or adapt based on prevailing conditions. The level of sophistication of these adaptive algorithms varies significantly. **Table 3-2** summarizes several types of ramp metering algorithms, and a brief discussion of each is provided below.

Table 3-2 Ramp Metering Strategy Comparison

Characteristic	Strategy				
		Adaptive Algorithms			
	Fixed-Timed	Gap Acceptance Merge Control	Local Traffic Responsive Control	Modified Coordinated Control (Helper Ramps)	Coordinated/ Global Traffic Responsive Control
Optimization of Freeway Operations	fair	fair	fair	good	excellent
Responsiveness to Daily Fluctuations	none	good	fair	good	excellent
Responsiveness to Incidents	none	fair	fair	fair	excellent
Responsiveness to Other Ramps	fair	poor	poor	good	excellent
Effectiveness at Limiting Spillback	fair	fair	fair	good	good

Ease of Developing Plans	easy	moderate	moderate	difficult	very difficult
Hardware/ Communications Requirements	low	low	moderate	moderate	high
Equity	good	fair	poor	fair	good

3.3.1 Fixed-timed

Fixed time ramp metering is the simplest form of metering and is used to break up platoons of entering vehicles into single vehicle entities. This strategy is typically used where traffic conditions are predictable and the metering rate is programmed by time-of-day. Under this strategy, ramp meters are fixed using pre-set metering rates for specific times (e.g., 700 vehicles/hour from 7:00 to 7:45 AM, and then 600 vehicles/hour from 7:45 to 9:00 AM, etc.). The rate is usually calculated in advance based on historical data. A very basic strategy is to set the rate as the difference between the downstream capacity and the upstream demand. The rate could be reduced further to accommodate downstream on-ramps.

The advantages of pre-timed ramp metering control are that it requires the least expensive hardware/communications equipment, with no requirement for detection, and it can be determined in advance. Also, drivers at a particular ramp will normally have approximately the same queues and delays from day to day. As a relatively simple approach, it can be used as a first-cut solution until more sophisticated algorithms are available. The biggest drawback is that it is not responsive to daily traffic fluctuations, so ramp metering may have to be overly restrictive to handle the worst case day, or else traffic may overload the system on particularly high-volume days. This may lead to higher violations of the meter (Pearson, Black and Wanat 2001) and additional driver frustration when the freeway flows are low since there is less optimization of the release of queued vehicles. Motorists often perceive this method of operation as non-responsive. Also, this approach cannot be used for incident management.

3.3.2 Gap Acceptance Merge Control

With this strategy, mainline detectors are used to indicate when upstream gaps in traffic are large enough to release vehicles from the ramp meters. This approach is very responsive to short-term traffic fluctuations, but it must be set to allow for the least capable drivers. Also, gaps may change as a result of last-second lane changes. Another disadvantage is that this is an example of an isolated strategy, so the system impacts of metering rates are not considered. This system does not work well when there is heavy traffic, and has been infrequently used.

3.3.3 Local Traffic Responsive Control

This is also an isolated strategy, but one uses input from detectors in the vicinity of the ramp to determine the discharge rate on the ramp. With this solution the relationship between freeway flow and ramp demand is pre-defined in the controller data. The detectors (shown in **Figure 3-2**) count the ramp demand, the ramp discharge and the freeway traffic. A response table is stored in the local controller and an appropriate metering rate for the ramp is implemented. This method treats ramps as discrete units rather than as part of a system.

It is responsive to short-term changes in traffic conditions, and can minimize the adverse effects caused by dynamic congestion changes or incidents. Since it accommodates ramp queuing and uses a higher meter rate when freeway flow is lower, it gives the appearance of an intelligent response and usually maintains a reasonable violation rate.

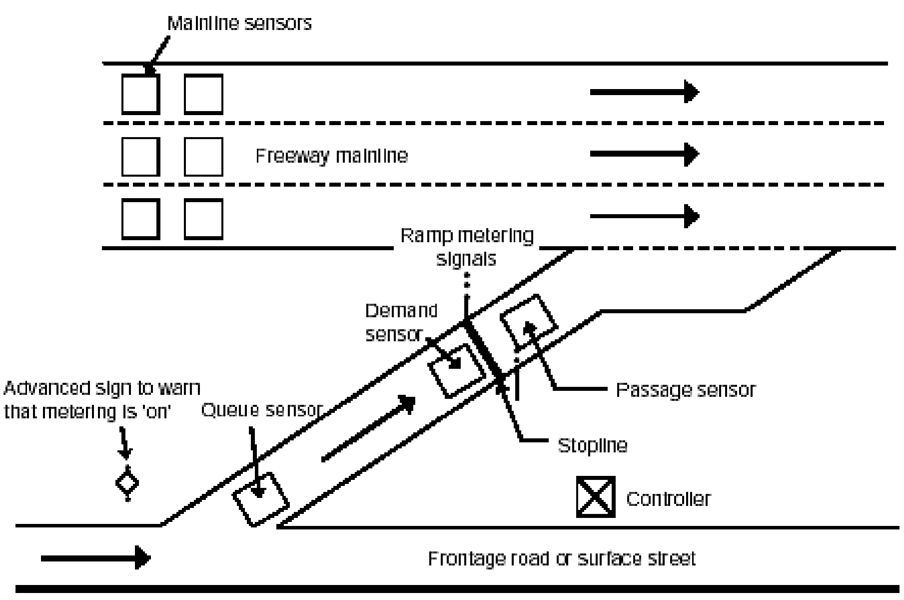

Figure 3-2 Typical Detector Layout for Local Traffic Responsive Ramp Metering

Source: U.S. Department of Transporation Federal Highway Administration 2008

The main disadvantage of local traffic responsive control is that it is not effective until congestion reaches the immediate area of the ramp in question. Also, it is a reactive strategy that cannot be used to prevent congestion downstream.

Caltrans District 4 currently employs a version of this strategy, referred to as TOS 2.0, for ramp meters in the Bay Area. Under the TOS 2.0 algorithm, the metering rate is set based on the occupancy level measured at the detector station upstream of the on-ramp. Another example of a local traffic responsive control algorithm is Asservissement LINeaire d'entrée Autroutiere (ALINEA). ALINEA utilizes detection downstream of the merge area, and incorporates a predictive elements in which the history of performance on the ramp is factored into the ramp discharge determination.

3.3.4 Modified Coordinated Control (Helper Ramps)

This approach ties together the controls for pairs or small groups of individual on-ramps, and as such is an intermediate step between local and coordinated/global traffic responsive control. The metering rate at a particular ramp is reduced to improve mainline operations, but not below a minimum rate, or the point at which spillback is detected at the queue detector. When the rate cannot be reduced further, it calls on an upstream or downstream "helper" ramp to reduce the on-ramp flow. This strategy is easier and less costly to implement than a global system, but still achieves some of the system benefits of that approach. The limitation of the helper ramps system is that even the modified coordinated control may not be an optimum solution for the system. Examples of modified coordinated control algorithms include Zone and Helper.

3.3.5 Coordinated/Global Traffic Responsive Control

This control strategy seeks to optimize a multiple-ramp section of freeway, often with the control of a bottleneck as the ultimate goal (Pearson, Black and Wanat 2001). The operations strategy is similar to the Local Traffic Responsive Ramp Metering; however, multiple response strategies can be deployed based on modeled conditions through the use of a virtual intelligence engine. the metering rate at each ramp is set by a central computer (generally at a traffic operations center). In calculating metering rates, the performance for the entire freeway is considered, rather than locally optimizing conditions at each ramp. This approach gives the best systemwide control, and can even be tied to a regional system that optimizes signal timing on surface streets. Also, it is flexible in response to local and daily fluctuations in demand, as well as incidents.

The typical ramp layout identified by FHWA is shown in **Figure 3-3**. This may be different from existing typical ramp layouts installed on other corridors by Caltrans District 4.

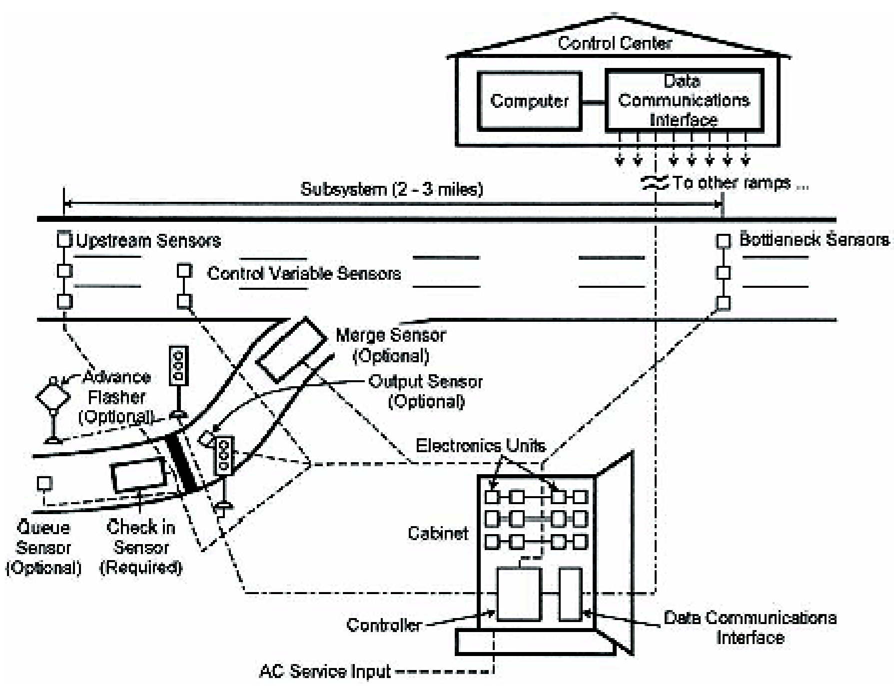

Figure 3-3 Typical Detector Requirements for Adaptive Ramp Metering

Source: U.S. Department of Transportation Federal Highway Administration 2008

The primary disadvantage is the cost of this type of system. It is also the most difficult to implement and the algorithms for implementing global control are still being developed.

Coordinated control strategies have been implemented in numerous areas including Minneapolis, Paris, and Amsterdam. One example of ARM now available is a software application called Corridor Wide Adaptive Ramp Metering (CWARM). CWARM is a two-level algorithm that has both local and global control. The local control is based on local density, while the global control adjusts ramp metering rates by reducing volume from ramps upstream of a bottleneck. The bottlenecks are determined based on predicted traffic conditions; they are not measured. This method has the ability to prevent congestion, instead of reacting to existing conditions. Yet, CWARM is only as robust as its predictions and is highly dependent on a reliable detection system. Hence, a comprehensive mainline detection system needs to be in place. Other examples of available systems include Bottleneck, ACCEZZ, Demand-Capacity, SWARM (Systemwide Adaptive Ramp Metering), Fuzzy Logic, and HERO.

4 I-80 ICM PROJECT RAMP METERING PARAMETERS

An important component of the I-80 ICM Project is the implementation of ramp metering within the study corridor. This chapter outlines the ramp metering-related design and operating parameters proposed as part of the I-80 ICM Project.

4.1 Geographic Limits

As noted, the I-80 ICM Project covers the freeway and important arterials in the I-80 corridor between the Carquinez Bridge (Contra Costa County) and San Francisco Bay Bridge Toll Plaza (Alameda County). As part of the I-80 ICM project, it is proposed that all ramps onto I-80 within these limits be equipped with ramp metering equipment with the following exceptions:

- Richmond Parkway HOV on-ramp to westbound I-80;
- Cutting Boulevard HOV on-ramp to eastbound I-80;
- I-580 eastbound connector to westbound I-80 (from Richmond and the Richmond-San Rafael Bridge to Berkeley and Oakland);
- I-580 westbound connector to westbound I-80 (from Oakland to the Bay Bridge);
- I-580 westbound connector to eastbound I-80 (from Oakland to Berkeley and points east);
- I-880 northbound connector to westbound I-80 (from Oakland to the Bay Bridge); and
- I-880 northbound connector to eastbound I-80 (from Oakland to Berkeley and points east).

It should be noted that two of the freeway-to-freeway connectors listed above have been identified as candidates for metering as a way to provide further improvement to I-80 and to reduce the metering load on the other I-80 ramp meters. These two are the I-580 eastbound connector to westbound I-80, and the I-880 northbound connector to eastbound I-80. Metering of the I-580 eastbound connector is currently being investigated, however no decision has not been made at this time

It is also important to note that even though all the on- ramps will be equipped with the ramp metering equipment within the study limits; not all meters will be turned on (active) during any given hour. Whether or not a meter is active during a specific time will be based on the prevailing traffic conditions. For example, current conditions and those forecast for 2015 indicate that during the AM peak period there is no congestion in the eastbound direction, and therefore the meters at all eastbound ramps could be turned off during that period. Conversely, there is significant congestion during both the AM and PM peak periods in the westbound direction suggesting that active ramp metering throughout the corridor may be effective during both periods.

4.2 Time Period

It is proposed that the ramp meters operate during the weekday peak periods. For the expected 2015 implementation timeframe, these peak periods are assumed to be:

- AM Peak Period: 5:00 AM to 10:00 AM.
- PM Peak Period: 14:00 AM to 19:00 PM

However, it is recognized that the peak time of day and duration can vary greatly between different segments and directions of the freeway system, as well as day-to-day. In some periods (i.e. peak hour shoulder), if it is needed, some on-ramp meters can be set to solid (continuous) green. Additionally some on-ramp metering operation can extend beyond the periods assumed above (i.e. beyond 10 AM). In short, the ramp meters should operate when conditions warrant within the peak periods. Therefore, it is recommended that the ramp metering system not be based on fixed time, but rather utilize advanced software systems plus mainline and ramp detection to control the operation of the meters.

Additionally, it is anticipated that the ramp metering system may include the capability to be activated at other times of the time, as appropriate, to support special event and incident management activities.

4.3 Queue Detection and Limits

Under the I-80 ICM Project, it is proposed that all metered ramps be equipped with queue detectors. As described in Chapter 3, these are detectors located at the upstream end of the ramps. When the occupancy levels on this detector reach a certain threshold (indicating a queue), the metering rates are automatically increased to help dissipate the queued traffic.

In general, ramp meter queues should be limited to the storage available on each on-ramp. However, at some locations additional storage may be possible on the surface streets approaching a ramp if such queuing does not impact other local street movements. This determination must be made on a case-by-case basis with consultant between Caltrans and local jurisdictions.

4.4 HOV Treatment

Current Caltrans' ramp design policy indicates that an HOV preferential lane should be provided on any on-ramp where metering was implemented. Practically speaking, various physical and funding constraints limit the ability to provide these lanes in the I-80 corridor.

As part of the I-80 ICM Project, HOV preferential lanes are included at the following locations:

- SR 4 on-ramp to westbound I-80;
- Eastbound Hilltop Drive diagonal on-ramp to westbound I-80;
- Buchanan Street on-ramp to westbound I-80;
- Gilman Street on-ramp to westbound I-80;
- University Avenue on-ramp to westbound I-80
- Ashby Avenue on-ramp to westbound I-80

- El Portal Drive on-ramp to eastbound I-80;
- Westbound Hilltop Drive diagonal on-ramp to eastbound I-80; and
- Eastbound Richmond Parkway loop on-ramp to eastbound I-80.

These locations were included because the HOV preferential lanes can be provided with minimal cost, and generally require only striping and signing improvements.

In the longer term, it is recommended that consideration be given to the provision of HOV preferential lanes as part of any future project impacting interchanges and ramps along the project segment I-80. Additionally, separate funding may be sought specifically for ramp improvements that support the effective application of ramp metering within the study corridor.

4.5 Control Strategy and Metering Rates

A comprehensive assessment of available ramp metering strategies and algorithms has been undertaken as part of the development of the I-80 ICM Project Concept of Operations and System Requirements. This effort concluded that corridor-wide, coordinated ramp metering is an appropriate strategy for use in this corridor. Furthermore, it was recognized that local traffic responsive ramp metering, in the form of the current District TOS 2.0 algorithm, is a logical interim step on the path to a corridor-wide system and is the minimum acceptable level of sophistication for this corridor.

4.5.1 Near-Term

In the near-term, it is anticipated that the ramp metering control algorithm for I-80 would be based on the existing Caltrans Traffic Operations System (TOS) v2.1.1 program used throughput the Bay Area. The TOS program allows meters to be operated under local traffic-responsive or pre-timed metering control. It is anticipated that local traffic-responsive control would be utilized for the I-80 corridor.

In short, under traffic responsive control, the metering rate is set based on the occupancy level measured at the detector station upstream of the on-ramp. The TOS program currently allows for the definition of six traffic-responsive plans for controller (for the purposes of this project, it was assumed a separate controller would be provided for each ramp. Each plan applies to a specified time period and includes sixteen entries, which are actually lookup tables that associate a set of occupancy levels with a set of metering rates. Typically, at higher occupancy levels, indicating increasing congestion, a more restrictive (lower) metering rate is applied.

An example of a TOS 2.0 traffic-responsive plan is shown in **Table 4-1.** As noted above, a metering plan is essentially a lookup table where if occupancy is higher than a certain occupancy level, the corresponding metering rate is applied. For example, under Plan 1, if the current mainline occupancy is higher than 7%, a metering rate of 850 would be applied; if the occupancy reaches 9%, the metering rate is dropped to 750; if the occupancy is further increased to 17%, the metering rate is dropped to 300. Although TOS supports 16 entries or metering levels, Plan 1 only has 6 levels and Plan 2 has 4 levels.

Table 4-1 TOS Ramp Metering Plan Example

Metering Level	Plan 1		Plan 2	
	Occupancy	Rate (veh/hr)	Occupancy	Rate (veh/hr)
0	7%	850	7%	850
1	9%	750	9%	510
2	11%	600	14%	480
3	13%	500	19%	450
4	15%	400		
5	17%	300		
…				
…				

The TOS program also provides for queue override. When a queue is detected using the queue detector located at the upstream end of the ramp, the ramp metering rate can be increased by a specified increment, with an additional increase added every 15-second interval, until the queue is no longer detected.

As will be described in the following chapter, a set of TOS 2.0 ramp metering look-up tables were developed to support the evaluation of ramp metering under projected 2015 conditions. While this involved the definition of specific metering plans for individual ramps, those rates were based on projections of future demands. In reality, the implemented rates will be based actual observed volumes and conditions. Caltrans' ramp meter design guidelines require that geometric ramp design for operational improvement projects (including ramp meters) must be based on current (less than two years old) peak-hour traffic volumes. Even then, the rates defined prior to implementation will be subject to fine-tuning in the field after implementation. As such, it is unrealistic for this report to identify specific 2015 ramp metering rates.

4.5.2 Long-Term

Eventually, it is anticipated that a coordinated, corridor-wide adaptive ramp metering program would be implemented in this corridor. It is assumed that this capability will be developed as an I-80 management application within the upgraded D4 RTMC ATMS ramp metering module currently under development.

Work is currently underway to define the requirements for such a program and to assess the capability of several existing adaptive programs in meeting these requirements. As part of this effort, three existing programs have been selected as suitable for application within the I-80 corridor. These programs are:

- Fuzzy Logic;
- SWARM/modified SWARM; and
- HERO.

Several other programs were eliminated from consideration for various reasons including not being corridor-based and lack of a deployment track record. The final decision on which adaptive program to implement will be made at a later date in consultation with the I-80 System Integrator based on the cost effectiveness of implementing each program.

4.6 Ramp Geometric Improvements

Often, ramp metering is implemented in association with ramp and interchange improvements that increase metering capacity or storage, thus enhancing the efficiency and effectiveness of ramp metering while also minimizing potential impacts.

Reflective of funding constraints, a limited set of geometric improvements are proposed as part of the I-80 ICM Project. In addition to the HOV preferential lanes listed in Section 4.4, these improvements include minor re-alignment of the onramps from SR 4 and Willow Avenue to eastbound I-80, and the widening of the SR 4 on-ramp to westbound I-80. In all cases, these improvements involve only minor physical changes, and emphasize striping and signing improvements. Other physical improvements to the ramps are beyond the resources of this project, but it is recommended that such improvements be considered as potential longer-term projects separate from the I-80 ICM Project.

5 INITIAL RAMP METERING ASSESSMENT

As part of the I-80 ICM Project evaluation, the benefits and impacts of ramp metering under 2015 conditions was examined. The results of this evaluation are presented in the *I-80 ICM Project Traffic Operations Analysis Report*, and are summarized in the following section. In addition, for this report, the on-ramps at each of the local interchanges within the project limits were assessed for 2035 conditions in regards to meter capacity and available storage. The results of that assessment are presented in Section 5.2.

5.1 2015 Operational Analysis

Detailed operational analysis of the proposed I-80 ICM Project, including ramp metering, was undertaken for 2015 conditions as part of the *I-80 ICM Project Traffic Operations Analysis Report.* That analysis utilized micro-simulation modeling, and examined both the AM and PM peak periods. The future year of 2015 was used as it represents the approximate opening date for the project

To build an understanding of the potential benefits of the ICM elements, combinations of the core ICM elements were assembled for comparison to 2015 No Build conditions. These core elements included the Ramp Metering, Variable Speed Limit, and Lane Control/Management applications. Alternatives were analyzed under two operating scenarios: 2015 Recurring (Non-Incident) Conditions, and 2015 Incident Conditions. For recurring conditions, the alternatives tested were:

- 2015 No Build
- 2015 with Ramp Metering
- 2015 with VSL (AM peak period only)
- 2015 with Ramp Metering + VSL

The alternatives tested under incident conditions included:

- 2015 No Build,
- 2015 Ramp Metering (AM peak period only)
- 2015 Ramp Metering + VSL (AM peak period only), and
- 2015 Ramp Metering + VSL + Lane Management.

In all cases involving ramp metering, the TOS 2.0 control strategy was assumed.

Based on the simulation and analysis of 2015 No Build conditions, it was determined that ramp metering could be applicable in the westbound direction during the AM peak period, and in both directions during the PM peak period. The congestion pattern, in terms of the limited magnitude and location at the start of the corridor, suggested that ramp metering would not be effective in the eastbound direction during the AM peak period.

The analysis of ramp metering required development of TOS 2.0 ramp metering look-up tables for each metered on-ramp (see section 4.5.1 for example of a TOS 2.0 metering look-up table). The first step in this process involved utilizing FREQ models of the study corridor to establish initial rates. FREQ was used to identify the optimized metering rate for each ramp and associated occupancy level for the upstream mainline segment given the forecasted demands. Depending on the magnitude of that occupancy level, additional metering levels were defined for lower occupancy ranges and less restrictive (higher) metering rates. Additionally, a final metering level for occupancies greater than that indicated by FREQ was also defined. In this case, the metering would be more restrictive (lower) than the rate identified by FREQ. For most ramps, multiple look-up tables were defined for different time slices within a peak period to reflect variations in the expected occupancy and metering rates.

These FREQ-generated look-up tables were then converted into and tested using the micro-simulation model. Based a review of the initial model runs, refinements to the metering rates and occupancies were made where appropriate to improve the effectiveness of ramp metering and minimize the impacts associated with excessive queuing.

This is similar to the actual process used in developing ramp metering plans. Observed traffic volume and condition data for the period just prior to implementation is used to construct an initial set of ramp metering plan tables. These tables are used for the initial implementation of ramp metering, but then field observations are performed and adjustments to the metering plans made as needed.

The assumed 2015 metering rates for each ramp resulting from the modeling process are summarized in **Table 5-1** and **Table 5-2** for the westbound and eastbound directions, respectively. Recognizing the capability of the TOS program to accept multiple plans for each ramp, metering rates are provided for each half-hour time slice to reflect the differing conditions throughout each period.

It is important to note that these rates were based on projections of future demands, and represent only the set of ramp metering rates used within the micro-simulation model for testing ramp metering under 2015 conditions. In reality, the implemented rates will be based actual observed volumes and conditions. Caltrans' ramp meter design guidelines require that geometric ramp design for operational improvement projects (including ramp meters) must be based on current (less than two years old) peak-hour traffic volumes. Even then, the rates defined prior to implementation will be subject to fine-tuning in the field after implementation. As such, it is unrealistic for this report to identify specific 2015 ramp metering rates.

Table 5-1 Initial TOS Control Strategy Ramp Metering Rates – 2015 Westbound

On-Ramp Location	Lanes		AM								PM									
	General Purpose	HOV	6:00-6:30	6:30-7:00	7:00-7:30	7:30-8:00	8:00-8:30	8:30-9:00	9:00-9:30	9:30-10:00	14:00-14:30	14:30-15:00	15:00-15:30	15:30-16:00	16:00-16:30	16:30-17:00	17:00-17:30	17:30-18:00	18:00-18:30	18:30-19:00
WESTBOUND																				
Loop on from San Pablo Ave	1	0	400	400	400	400	400	400	400	400	650	650	650	650	650	650	650	650	650	650
On from Cummings Skyway	1	0	400	400	400	400	400	400	400	400	650	650	650	650	650	650	650	650	650	650
On from Willow Ave	2	0	330	340	1000	900	900	900	900	900	650	650	650	650	650	650	650	650	650	650
On from EB/ On from 4	2	1	490	420	1520	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
On from Pinole Valley Rd	2	0	380	950	1300	1300	1300	1000	700	700	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
On from Appian Way	2	0	410	390	1100	1300	1760	1800	900	900	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Loop On from Richmond Pkwy	1	0	290	300	300	590	620	500	500	500	650	650	650	650	650	650	650	650	650	650
On HOV from Richmond Pkwy	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Loop On from Hilltop Dr	1	0	290	300	320	320	590	920	800	500	650	650	650	650	650	650	650	650	650	650
Diag On from EB Hilltop Dr	1	1	400	400	240	400	400	400	400	400	650	650	650	650	650	650	650	650	650	650
On from El Portal Dr	2	0	380	370	380	390	360	1080	1660	1740	900	900	900	900	900	900	900	900	900	900
On from San Pablo Dam	2	0	410	390	390	400	400	390	370	1130	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
On from Solano Ave/Humbildt St	1	0	300	310	720	690	770	830	500	500	650	650	650	650	650	650	650	650	650	650
On from Barrett	2	0	320	320	460	650	1120	1180	600	600	700	700	700	700	700	700	700	700	700	700
On from Potrero Ave	2	0	300	390	340	340	330	930	940	930	650	650	650	650	650	650	650	650	650	650
On from Carlson Blvd	2	0	260	270	500	500	500	400	400	400	700	700	700	700	700	700	700	700	700	700
On from Central Ave	1	0	260	290	580	600	700	700	700	700	650	650	650	650	650	650	650	650	650	650
On from John T Knowles Fwy / I-580 S	2	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
On from Buchanan St	1	1	260	280	340	350	810	950	930	930	900	900	900	900	900	900	900	900	900	900
On from Gilman St	1	1	240	240	300	300	300	790	730	900	500	500	500	500	500	500	500	500	500	500
On from University CD	1	1	240	240	900	900	900	900	800	800	750	750	750	750	750	750	750	750	750	750
On from Ashby Ave/Frontage Rd	2	1	240	240	370	640	900	900	900	900	900	900	900	900	900	900	900	900	900	900
Loop On from Captain/Frontage/ Powell	2	0	260	400	600	1510	1100	1000	1000	800	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Diag On from EB Powell	1	0	400	400	400	400	400	400	400	400	600	600	600	600	600	600	600	600	600	600

Table 5-2 Initial TOS Control Strategy Ramp Metering Rates – 2015 Eastbound

On-Ramp Location	Lanes		AM								PM									
	General Purpose	HOV	6:00-6:30	6:30-7:00	7:00-7:30	7:30-8:00	8:00-8:30	8:30-9:00	9:00-9:30	9:30-10:00	14:00-14:30	14:30-15:00	15:00-15:30	15:30-16:00	16:00-16:30	16:30-17:00	17:00-17:30	17:30-18:00	18:00-18:30	18:30-19:00
EASTBOUND																				
On from Powell St	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
On from WB Ashby Ave/Potter St	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1800	1800	1800	All Green	All Green	All Green	All Green	All Green	All Green	All Green
On from WB University	1	0	Off	Off	Off	Off	Off	Off	Off	Off	900	900	All Green	All Green	All Green	All Green	All Green	All Green	All Green	All Green
On from Gilman St	2	0	Off	Off	Off	Off	Off	Off	Off	Off	500	500	600	600	700	700	700	700	700	600
On from Buchanan St	1	0	Off	Off	Off	Off	Off	Off	Off	Off	700	700	700	700	700	700	700	700	700	700
On from Central Ave	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1800	1800	1800	1800	All Green	All Green	All Green	All Green	900	1800
On from Carlson Blvd	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
Loop on from Cutting Blvd	1	0	Off	Off	Off	Off	Off	Off	Off	Off	700	700	700	700	700	850	850	850	700	700
Diag on from WB Cutting Blvd	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
HOV diag on from Cutting Blvd	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
On from San Pablo Ave	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1800	1800	All Green	All Green	All Green	All Green	All Green	All Green	All Green	All Green
On from San Pablo Dam	1	0	Off	Off	Off	Off	Off	Off	Off	Off	800	800	800	800	800	800	800	800	800	800
On from El Portal Dr	1	1	Off	Off	Off	Off	Off	Off	Off	Off	900	900	900	900	900	900	All Green	All Green	900	900
Loop On from Hilltop Dr	1	0	Off	Off	Off	Off	Off	Off	Off	Off	800	800	800	800	800	800	800	800	800	800
Diag On from WB Hilltop Dr	1	1	Off	Off	Off	Off	Off	Off	Off	Off	900	900	900	900	900	900	900	900	900	900
Loop On from Richmond Pkwy	1	1	Off	Off	Off	Off	Off	Off	Off	Off	900	900	All Green	All Green	All Green	All Green	All Green	All Green	All Green	All Green
Diag On from WB Richmond Pkwy	1	0	Off	Off	Off	Off	Off	Off	Off	Off	650	650	800	800	800	800	800	800	600	600
Loop On from Appian	1	0	Off	Off	Off	Off	Off	Off	Off	Off	650	650	800	800	800	800	800	800	600	600
Diag On from WB Appian	2	0	Off	Off	Off	Off	Off	Off	Off	Off	800	800	800	800	800	800	800	800	800	800
On from Pinole Valley Rd	1	0	Off	Off	Off	Off	Off	Off	Off	Off	650	650	800	800	800	800	800	800	800	800
On from RTE 4	2	0	Off	Off	Off	Off	Off	Off	Off	Off	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
On from Willow Ave	1	0	Off	Off	Off	Off	Off	Off	Off	Off	900	900	900	900	900	900	900	900	900	900
On from Cummings Skyway	2	0	Off	Off	Off	Off	Off	Off	Off	Off	900	900	900	900	900	900	900	900	900	900
On from San Pablo Ave	1	0	Off	Off	Off	Off	Off	Off	Off	Off	900	900	900	900	900	900	900	900	900	900

This analysis indicated that under 2015 conditions Ramp Metering significantly improves freeway operations and provides an overall benefit to operations in the corridor. Specific findings from the analysis indicate that Ramp Metering:

- decreases the hours of delay on westbound I-80 by over 20% during both the AM and PM peak periods.
- increases speeds on westbound I-80 by 9% during the AM peak, and by 15% during the PM peak.
- provides only modest benefit in the eastbound direction during the PM peak period due to the congestion pattern (the primary congested segment is located at the start of the corridor) and the all-green operation at several on-ramps, notably those in the Emeryville/Berkeley area.
- shifts some delay to the on-ramps and arterial approaches, but would still yield an overall reduction in network hours of delay of 9% during the AM peak and 6% during the PM peak.
- produces average meter delays of about 30 seconds per vehicle during both the AM peak and PM peak.
- generates additional delays of over 1 minute and queue spillback onto local streets at a limited number of locations. In these cases, modifications can be made to the ramp metering rates and/or meter designs to mitigate or minimize these ramp delays and arterial impacts.
- is expected to have a generally minimal impact on trips originating within Contra Costa or Alameda Counties and destined for the points beyond the corridor boundaries during the AM peak period. Journey travel times for a broad sample of such trips indicate that in most cases ramp meter delay is offset by mainline speed improvement resulting in negligible change in overall travel time.
- will provide a benefit during the PM peak period to those trips destined for points within Contra Costa or Alameda Counties
- will not result in the diversion of trips from the freeway to parallel routes such as San Pablo, but can keep traffic on the freeway by discouraging drivers from hopping off the freeway and back on.
- will have an insignificant or minor impact to the arterial network as a whole and San Pablo, in particular, with respect to hours of delay and average speeds.
- can lead to accident rate reductions of 20% to 50%[2]. The benefits of an accident rate reduction include a lower number of injuries and fatalities, a decrease in property damage costs, and a reduction in non-recurring delay.
- can produce greenhouse benefits in the form of reduced emissions and fuel consumption as a result of reduced congestion and smoother flow.

[2] Freeway Management and Operations Handbook, FHWA, 2003 (revised 2006)

The evaluation of the With Incident conditions for the AM peak period indicates that:

- Ramp Metering alone is projected to maintain improved performance within the upstream segments, but does not reduce delay within affected segment from Central to the I-580/I-880 split. The result is an overall 8% reduction in hours of delay for westbound I-80.
- the addition of VSL results in the slowing of traffic on the upstream links, but then a modest benefit within the "incident" segment from Central to the 580/880 Split. The overall impact of the Ramp Metering + VSL alternative is insignificant compared to the Base alternative under Incident conditions.
- Neither the Ramp Metering alone nor Ramp Metering + VSL alternative is projected to have a significant impact on the flow or throughput past the incident location.

A related finding is that modifications to the on-ramp designs would be beneficial to improve the effectiveness of Ramp Metering and minimize impacts to local streets. This analysis revealed several locations where either the on-ramp demands exceed the ramp meter capacity or where platoons of traffic released from upstream signals overwhelm limited storage provided on the ramp based on the currently proposed designs. On-ramp locations of potential concern include:

- Westbound-
  - SR 4
  - San Pablo Dam
  - Buchanan
  - Powell

- Eastbound-
  - Powell
  - Ashby
  - University
  - Central
  - Carlson
  - San Pablo/Roosevelt
  - El Portal on-ramp
  - Richmond loop on-ramp

One potential operational strategy to avoid significant negative impacts at these locations is to allow for all-green operation of the ramp meter during appropriate intervals within the peak period. This approach, however, reduces the effectiveness of ramp metering as it essentially "unmeters" those ramps. In addition, all-green operation for a prolonged interval creates holes in the system, and familiar drivers may take advantage of this and divert from other ramps.

The more effective approach is to undertake physical improvements to remedy the situation. In some cases, a low-cost solution could include converting a proposed HOV priority lane into a second general purpose lane at the meter. In other cases, higher-cost capital improvements may be appropriate. These capital improvements may include ramp widening provide for an additional general purpose lane, and widening or lengthening a ramp to provide additional storage.

While the possibility of converting proposed HOV priority lanes to general-purpose lanes where applicable should be considered within the context of the I-80 ICM Project, other physical improvements to the ramps as suggested above are beyond the resources of this project. As such, it is recommended that these improvements be considered as potential longer-term projects separate from the I-80 ICM Project.

Based on the analysis conducted for this report, suggested ramp improvements intended to improve the effectiveness of ramp metering and minimize impacts to local arterials include:

- Westbound-
    - Buchanan on-ramp – convert proposed HOV priority lane to general-purpose lane, or widen ramp to provide second general-purpose lane.

- Eastbound-
    - Ashby on-ramp – modify ramp to allow traffic from Ashby to use both metered lanes. The current design provides separate metered lanes for traffic from Ashby and from Potter.
    - University on-ramp – modify ramp to provide second general-purpose lane at meter.
    - San Pablo/Roosevelt on-ramp – reconfigure ramp to provide additional storage.
    - El Portal on-ramp – convert proposed HOV priority lane to general-purpose lane, or widen ramp to provide second general-purpose lane.
    - Richmond loop on-ramp - convert proposed HOV priority lane to general-purpose lane, or widen ramp to provide second general-purpose lane.

While the possibility of converting proposed HOV priority lanes to general-purpose lanes should be considered within the context of the I-80 ICM Project, other physical improvements to the ramps as suggested above are beyond the resources of this project. Similarly, mitigation of potential concerns at several of the ramps listed would require major improvements to the interchanges. As such, it is recommended that these improvements be considered as potential longer-term projects separate from the I-80 ICM Project.

Further discussion and details of this evaluation are presented in the *I-80 ICM Project Traffic Operations Analysis Report.*

5.2 2035 On-Ramp Geometric Assessment

The on-ramps at each of the local interchanges within the project limits were assessed for 2035 demands in regard to the adequacy of the proposed I-80 ICM project ramp design to accommodate ramp metering. Two elements were examined: meter capacity and available storage. The goal of this assessment was to determine whether the ramps have the necessary metering capacity and storage to accommodate potential ramp meter-related queues and to highlight those locations where improvements may be appropriate.

This assessment took into consideration the peak hour demands, the number of lanes at the meter limit line, and the storage distance available from the limit line back to the terminus of the ramp. Based on the number and type of lanes at the meter limit line, the capacity of the meter (assuming a maximum metering rate of 900 vph per general purpose lane) was determined and compared to the peak hour demand. In cases where the demand exceeded the meter capacity, the resulting queue was determined and compared to the available ramp storage.

The results of this assessment for 2035 conditions are presented in **Table 5-3**. As shown in the table, six westbound on ramps are expected to have AM peak hour demands that exceed the maximum meter capacity and the resulting ramp meter queues that would extend beyond the limits of the ramp. During the PM peak hour, six eastbound on ramps and two westbound on ramps are expected to have peak hour demands that exceed the maximum meter capacity and resulting ramp meter queues that would extend beyond the limits of the ramp.

These ramps include several of those identified as part of the 2015 analysis as being of potential concern. New locations appearing in the 2035 assessment include:

- Westbound
    - Cummings Skyway
    - Hilltop loop
    - Solano/Humboldt
    - Central
- Eastbound
    - San Pablo Dam

As described in the previous section, potential measures to mitigate the impacts at these locations include all-green operation, widening the on-ramp to provide additional capacity or storage, or reconfiguring the interchange. It is recommended that these improvements be considered as potential longer-term projects separate from the I-80 ICM Project.

However, it is important to note the level of uncertainty inherent in the forecasts themselves. Overall, the 2035 forecasts suggest a high degree of saturation and congestion on both the freeway and arterial network during both peak periods. In turn, the high demand levels used in this analysis, and resulting delays and queues, may not be realized. Furthermore, if long delays occur at select ramps, it may be expected that some trips will divert to alternate ramps providing more uniform demands.

Table 5-3 On-Ramp Assessment of Future Conditions - 2035

I-80 On-Ramp	Future (2035) Peak Hour Demand						Configuration at Meter[i]				Demand Exceeds Meter Capacity		Expected Queue (veh)[ii]		Proposed I-80 ICM On-Ramp Improvements
	Total Demand		GP Lane Demand		HOV Lane Demand[iii]		# of Lanes		Storage Length (ft)[iv]	Storage Capacity (veh)[v]					
	AM	PM	AM	PM	AM	PM	GP	HOV			AM	PM	AM	PM	
Eastbound (AM Peak Hour 7:00-8:00 AM, PM Peak Hour 4:00-5:00 PM)															
EB on from Powell St	528	1,914	528	1,914			2	0	250	17	-	YES	-	97	
EB on fr WB Ashby Ave/Potter St	209	1,184	209	1,184			2	0	823	55	-	-	-	-	
EB on from WB University	593	1,223	593	1,223			1	0	450	15	-	YES	-	308	
EB on from Gilman St	1,078	934	1,078	934			2	0	450	30	-	-	-	-	
EB on fr Buchanan St	649	696	649	696			1	0	1,130	38	-	-	-	-	
EB on from Central Ave	607	861	607	861			2	0	280	19	-	-	-	-	
EB on from Carlson Blvd	640	980	640	980			2	0	540	36	-	-	-	-	
EB loop on fr EB Cutting Blvd	412	495	412	495			1	0	400	13	-	-	-	-	
EB diag on fr WB Cutting Blvd	498	1,103	498	1,103			2	0	400	27	-	-	-	-	
EB HOV diag on fr Cutting Blvd (on left)	39	206	0	0	39	206	0	1	-	-	-	-	-	-	
EB on from San Pablo Ave	675	1,267	675	1,267			2	0	200	13	-	-	-	-	

I-80 On-Ramp	Future (2035) Peak Hour Demand						Configuration at Meter[i]				Demand Exceeds Meter Capacity		Expected Queue (veh)[ii]		Proposed I-80 ICM On-Ramp Improvements
	Total Demand		GP Lane Demand		HOV Lane Demand[iii]		# of Lanes		Storage Length (ft)[iv]	Storage Capacity (veh)[v]					
	AM	PM	AM	PM	AM	PM	GP	HOV			AM	PM	AM	PM	
EB on from San Pablo Dam	587	1,135	587	1,135			1	0	560	19	-	YES	-	216	
EB on from El Portal Dr	545	1,483	474	1,290	49	79	1	1	750	25	-	YES	-	365	HOV Bypass Lane
EB loop on fr EB Hilltop Dr	320	958	320	958			1	0	780	26	-	YES	-	32	
EB diag on fr WB Hilltop Dr	481	330	419	287	29	53	1	1	700	23	-	-	-	-	HOV Bypass Lane
EB loop on fr EB Richmond Pkwy	838	1,440	729	1,253	100	58	1	1	650	22	-	YES	-	331	HOV Bypass Lane
EB diag on fr WB Richmond Pkwy	23	292	23	292			1	0	1,000	33	-	-	-	-	
EB loop on fr EB Appian	285	467	285	467			1	0	550	18	-	-	-	-	
EB diag on fr WB Appian	464	560	464	560			2	0	460	31	-	-	-	-	
EB on from Pinole Valley Rd	488	435	488	435			1	0	710	24	-	-	-	-	
EB on fr RTE 4	701	78	701	78			2	0	890	59	-	-	-	-	Ramp Alignment
EB on from Willow Ave	426	230	426	230			1	0	900	30	-	-	-	-	Ramp Alignment
EB on from Cummings Skyway	208	1,406	208	1,406			2	0	700	47	-	-	-	-	Additional Lane
EB on fr San Pablo Ave/Pomona St	176	652	176	652			1	0	760	25	-	-	-	-	

I-80 On-Ramp	Future (2035) Peak Hour Demand						Configuration at Meter[i]				Demand Exceeds Meter Capacity		Expected Queue (veh)[ii]		Proposed I-80 ICM On-Ramp Improvements
	Total Demand		GP Lane Demand		HOV Lane Demand[iii]		# of Lanes		Storage Length (ft)[iv]	Storage Capacity (veh)[v]					
	AM	PM	AM	PM	AM	PM	GP	HOV			AM	PM	AM	PM	
Westbound (AM Peak Hour 6:00-7:00 AM, PM Peak Hour 5:00-6:00 PM)															
WB loop on fr San Pablo Ave/Pomona St	94	221	94	221			1	0	1,390	46	-	-	-	-	
WB on from Cummings Skyway	954	29	954	29			1	0	400	13	YES	-	41	-	
WB on from Willow Ave	1,497	537	1,497	537			2	0	740	49	-	-	-	-	
WB on fr EB/WB on fr WB 4	2,693	2,350	2,155	2,045	458	259	2	1	1,415	94	YES	YES	261	151	HOV Bypass Lane, Widening
WB on from Pinole Valley Rd	607	748	607	748			2	0	530	35	-	-	-	-	
WB on from Appian Way	963	896	963	896			2	0	678	45	-	-	-	-	
WB loop on fr Richmond Pkwy	235	834	235	834			1	0	650	22	-	-	-	-	
WB on HOV from Richmond Pkwy	136	93	0	0	136	93	0	1	-	-	-	-	-	-	
WB loop on fr WB Hilltop Dr	957	706	957	706			1	0	540	18	YES	-	39	-	
WB diag on fr EB Hilltop Dr	561	10	448	9	51	1	1	1	970	32	-	-	-	-	HOV Bypass Lane
WB on from El Portal Dr	1,254	639	1,254	639			2	0	300	20	-	-	-	-	
WB on from San Pablo Dam	1,085	722	1,085	722			2	0	220	15	-	-	-	-	
WB on from Solano Ave/Humbildt St	1,199	372	1,199	372			1	0	200	7	YES	-	292	-	

I-80 On-Ramp	Future (2035) Peak Hour Demand						Configuration at Meter[i]				Demand Exceeds Meter Capacity		Expected Queue (veh)[ii]		Proposed I-80 ICM On-Ramp Improvements
	Total Demand		GP Lane Demand		HOV Lane Demand[iii]		# of Lanes		Storage Length (ft)[iv]	Storage Capacity (veh)[v]					
	AM	PM	AM	PM	AM	PM	GP	HOV			AM	PM	AM	PM	
WB on from Barrett	1,360	625	1,360	625			2	0	550	37	-	-	-	-	
WB on from Potrero Ave	1,035	391	1,035	391			2	0	865	58	-	-	-	-	
WB on from Carlson Blvd	1,654	322	1,654	322			2	0	300	20	-	-	-	-	
WB on from Central Ave	1,080	545	1,080	545			1	0	300	10	YES	-	170	-	
WB on fr John T Knowles Fwy / I-580 S	2,814	2,992	2,814	2,992			2	0	-	-			-	-	
WB on fr Buchanan St	1,547	552	1,237	481	340	88	1	1	750	25	YES	-	312	-	HOV Bypass Lane
WB on from Gilman St	1,092	603	874	524	66	24	1	1	1,060	35	-	-	-	-	HOV Bypass Lane
WB on fr University CD	90	878	72	764	4	44	1	1	465	16	-	-	-	-	HOV Bypass Lane
WB on fr WB Ashby Ave/Frontage Rd	610	916	488	797	31	37	2	1	1,800	120	-	-	-	-	HOV Bypass Lane
WB loop on fr Captain/Frontage/WB Powell	690	3,177	690	3,177			2	0	200	13	-	YES	-	1,364	
WB diag on fr EB Powell	211	475	211	475			1	0	2,150	72	-	-	-	-	

[i] Configuration is based on the proposed I-80 project ramp metering design
[ii] Ramp meter queue expected beyond storage if meter is set at maximum metering 900 vphpl
[iii] Applies only where HOV preferential lane is provided. HOV Demand is calculated based on the HOV percentage derived from the travel demand forecast models
[iv] Storage length is for each GP lane
[v] Vehicular storage capacity for all GP lanes based on 30 feet per vehicle.