A Case for Freeway Mainline Metering

KEVIN A. HABOIAN

In this work, the merits of freeway mainline metering as a means of better managing freeway traffic congestion are explored. Freeway mainline metering involves controlling the amount of traffic entering a freeway segment to provide improved travel downstream of the control area. To date, mainline metering has not been applied to a typical urban freeway system, although the concept has been applied successfully to bridges and tunnels. Experiences at these bridges and tunnels indicate that in the presence of a bottleneck, regulating the number of vehicles through the bottleneck will result in improved freeway operations. This study investigates whether regulating mainline vehicle movements can also improve freeway operations without the presence of a bottleneck. Also addressed in this work is whether mainline metering can provide additional benefits over and above typical ramp metering. To evaluate the above hypotheses, the INTRAS simulation model was used to replicate freeway traffic operations. The mainline, metering evaluation was based on a variety of mainline volume and on-ramp control conditions. The results indicate that mainline metering can improve freeway operations downstream of the mainline meter. Most importantly, this can be accomplished without increasing the overall delay for vehicles originating upstream of the metering location. In addition, vehicles accessing the freeway from metered on-ramps downstream of the mainline meter are no longer entering a congested freeway mainline, thus reducing overall travel time. These findings appear to indicate that mainline metering is an appropriate freeway management tool.

Freeway mainline metering, which involves controlling the amount of traffic entering a freeway segment to provide improved travel downstream of the control area, is a concept that has previously invoked fear in many transportation engineers and public representatives. This fear stems from perceptions of queues, travel delays, and accidents that would increase congestion and travel times beyond those being experienced without the mainline metering control strategy. As a result of this fear, there has been very limited application of mainline metering and very little empirical data from which to confirm or challenge the above perception.

Consequently, transportation professionals have employed more accepted control strategies as a means of managing congestion. Such strategies have included ramp metering, high occupancy vehicle (HOV) lanes, variable message signs, highway advisory radio, incident response teams, etc. Though these strategies have improved operations on many freeways and highways, even the most sophisticated combination of these strategies has failed to manage congestion to ensure optimal traffic operations. By the year 2005, delay caused by congestion is projected to be five times what it was in 1984 (*1*).

The essential problem is that all inputs (defined in this paper as vehicles entering a section of the freeway via either on-ramps or the upstream mainline) to the freeway are not properly managed. Until they are, freeways will continue to be susceptible to gridlock conditions. It is appropriate to consider traffic management strategies that can better manage freeway operations, including strategies that manage or control the freeway mainline. In this work, the merits of freeway mainline metering to better manage freeway traffic congestion are explored in greater detail.

Parsons Brinckerhoff Quade & Douglas, Inc., 505 South Main Street, Suite 900, Orange, Calif. 92668.

PREVIOUS MAINLINE METERING EXPERIENCE

To date there has been no application of mainline metering on an urban freeway system. However, this concept has been applied successfully to bridges and tunnels and, to a limited extent, freeway-to-freeway connector movements in California, Minnesota, and Washington (*2*). Mainline metering examples discussed below include the San Francisco-Oakland Bay Bridge in Northern California, the Hampton Roads Bridge-Tunnel in Southeastern Virginia, the Baltimore Harbor Tunnel, and unregulated examples of mainline metering.

Bay Bridge

The Bay Bridge traffic management operation in Northern California is an example of mainline metering being used to increase downstream traffic volumes. The Bay Bridge is one of the few links across the San Francisco Bay that connects the cities of San Francisco and Oakland. During the a.m. peak period, three freeways converge onto the Bay Bridge to San Francisco. This traffic passes through a 22-lane toll plaza, of which several lanes are reserved for HOVs. Approximately 305 m (1000 ft) downstream of the toll plaza a metering bridge regulates the frequency of vehicles approaching the five lanes that cross the bay. HOV vehicles do not pay a toll and may travel through the metering area without stopping. Before the metering operation, downstream throughput on the bridge averaging approximately 8,200 to 8,300 vehicles per hour (vph). Implementation of the mainline metering resulted in downstream throughput on the bridge averaging 9,500 vph and sometimes even approaching 10,000 vph (McCrank, unpublished data). Thus, the Bay Bridge metering system increased downstream traffic volumes by approximately 15 percent.

In this example, the Bay Bridge serves as a bottleneck for commuters merging from three freeways desiring to cross the San Francisco Bay. Without mainline metering, the Bay Bridge experiences a drop in capacity. However, by managing the amount of traffic entering the bottleneck section, vehicle throughput on the bridge is increased.

Hampton Roads Bridge-Tunnel

The Hampton Roads Bridge-Tunnel is one of Southeastern Virginia's most important facilities, providing the only interstate link across the Hampton Roads Harbor. The combination bridge-tunnel-bridge connects the Hampton shore on the north to the Norfolk shore on the south. By July 1983, delays of up to 2 hrs were experienced, causing cars to overheat and increasing carbon monoxide (CO) levels within the tunnel. In August 1983, manually controlled mainline metering was initiated. This consisted of stopping traffic before the tunnel entrances when the vehicles within the tunnel slowed to 24.2 km/hr (15 mph) or less. When the tunnel was clear of traffic and the CO levels dropped, the traffic was released. In all cases, the vehicles that had been detained caught up with the vehicles that had not been detained before they reached the opposite shore. In effect, motorists who had been detained 5 to 8 min before entering the tunnel arrived at the same time that they would have if they had not been detained. Several benefits were derived from the mainline metering, including:

- Lower CO levels and less ventilation required;
- Lower tunnel temperatures and less stoppages caused by overheated vehicles;
- Free-flow traffic for longer periods with better throughput; and
- Traffic backups of shorter duration and length.

This form of mainline metering was found to be one of the most effective methods of managing the bridge-tunnel-bridge traffic during periods of heavy congestion (*3*). However, because of motorist complaints of being stopped before entering the tunnel, the manually controlled mainline metering operation was not continued.

Baltimore Harbor Tunnel

In the 1970s, the Department of Civil Engineering at the University of Maryland initiated a project entitled "The Study of Traffic Flow on a Restricted Facility." This study, sponsored by the Maryland State Highway Administration and the FHWA, utilized the Baltimore Harbor Tunnel as a test bed to analyze the concepts of traffic flow theory. One of the control strategies analyzed was the effects of a pretimed mainline metering system upstream of the entrance to the tunnel and downstream of the tunnel toll plaza. Traffic signals were located approximately 366 m (1200 ft) upstream of the tunnel portal, and pretimed metering scenarios for cycle lengths of 2, 3, and 4 min were evaluated. When metering was engaged, the red time varied between 7 and 10 sec and amber time was between 3 and 5 sec. The signals were only activated when traffic was congested from the tunnel portal to the merging area just downstream of the toll plaza. This corresponded to vehicular speeds of 32 to 40 km/hr (20 to 25 mph) as motorists passed the metering point. When the metering was not engaged, the signals were a continuous green.

This metering operation resulted in increased speeds within the tunnel bottleneck, in addition to an increased flow rate within the tunnel (*4*). Based on speed flow curves developed from the before and after metering operation, the study noted that the metering system had the potential to increase the capacity per lane by approximately 10 percent above the no-control condition. However, because of lack of political support, the mainline metering operation was not continued.

Unregulated Examples of Mainline Metering

Most commuters experience mainline metering without realizing it. Regulated mainline metering exists when overhead lane-use signals, similar to ramp meter signals, provide red and green indications to motorists. Mainline metering is also achieved in an unregulated fashion as a result of either a freeway incident or a reduction in freeway capacity (a lane drop).

Consider the case of an accident occurring on the freeway. Because of several factors, the accident results in a smaller number of vehicles traveling downstream. Motorists rubbernecking as they pass the accident, the accident itself blocking one or more lanes, and the need to stop traffic temporarily to allow emergency vehicles to access the accident scene are all factors contributing to the reduction in vehicular throughput. However, as motorists pass the accident scene, they find that downstream travel lanes are uncongested, enabling them to travel at free-flow conditions. The accident itself serves as a form of mainline meter. However, a traffic accident is an inefficient form of mainline meter that can overcompensate the desired effect. Accidents can severely restrict the number of vehicles that bypass the incident, resulting in unused downstream capacity that could otherwise be utilized more effectively through proper management.

Another form of unregulated mainline metering occurs where there is a reduction in downstream capacity. Consider a four-lane freeway that has a lane drop resulting in a three-lane facility. If the four-lane freeway is operating near capacity, the lane drop will serve as a bottleneck. As the freeway approaches capacity, a queue usually forms upstream of the bottleneck as vehicles maneuver into the three downstream travel lanes. Downstream of the lane drop, traffic conditions are usually better than upstream. The lane drop essentially functions as a mainline meter. However, as a result of vehicles maneuvering into the three lanes at the bottleneck location, downstream vehicular throughput is reduced to less than what could be achieved. This situation is analogous to the previous case studies. In each case there was a reduction in downstream capacity that limited the number of vehicles that could travel through the bottleneck. However, once a regulated mainline metering system was implemented, downstream vehicular throughput increased.

These examples of unregulated mainline metering were created because of a bottleneck condition. Even the previously discussed mainline metering experiences at the Bay Bridge, Hampton Roads Bridge-Tunnel, and Baltimore Harbor Tunnel were a result of bottleneck conditions at each location. The presence of a bottleneck creates the need to better manage the frequency of vehicles arriving at the bottleneck area. Without this management, experience has shown that there is a loss of downstream vehicular throughput and increased travel time as uncontrolled vehicles attempt to maneuver through the bottleneck location.

MAINLINE METERING RESEARCH OBJECTIVE

Existing freeway operations have demonstrated that, in the presence of a bottleneck condition or reduction in downstream capacity, regulating the number of vehicles through the bottleneck improves freeway operations. This research investigates whether regulating mainline vehicle movements can also provide improved freeway operations without the presence of a bottleneck.

During periods of heavy congestion, traffic density on the freeway can approach and exceed 96.6 vehicles per kilometers per lane (60 vehicles per mile per lane) (*5*). This results in the freeway operating in the unbalanced portion of the density-flow curve and a corresponding reduction in traffic flow efficiency. This traffic flow reduction, in the opinion of this author, can also be considered a reduction in capacity (Figure 1). In Condition 1, in which capacity exceeds demand, there is no congestion and traffic flows smoothly.

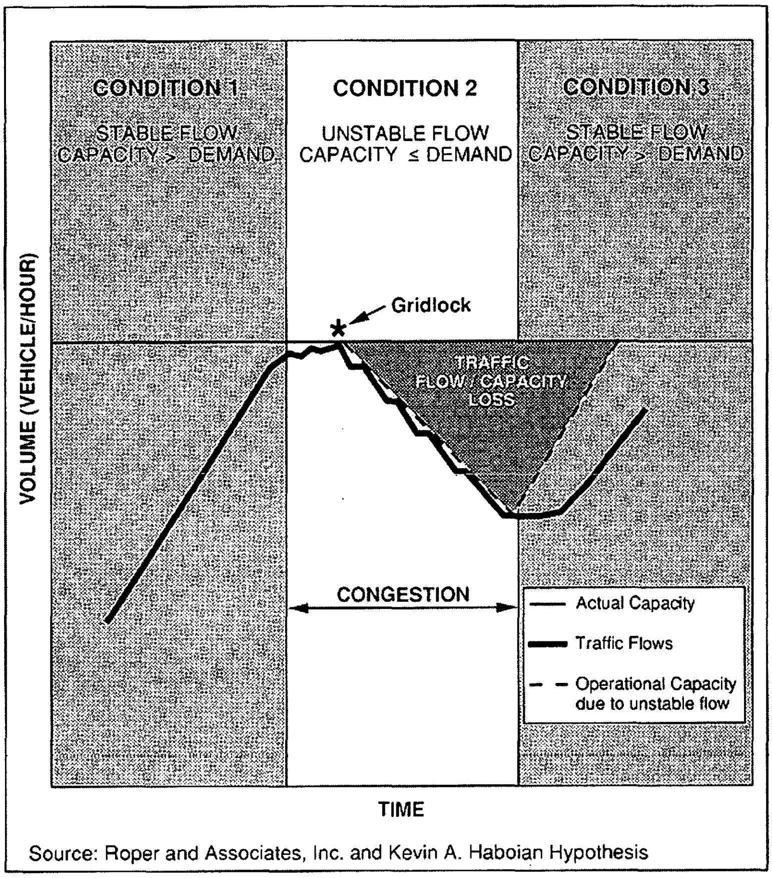

FIGURE 1 Traffic flow or capacity loss caused by congestion.

As demand builds to equal capacity, unstable flows are experienced and inefficient operation takes place. Finally, gridlock conditions occur and traffic flows fall sharply. This reduction in traffic flow can be referred to as the operational capacity caused by unstable flow. Under Condition 2, operation is unstable, inefficiencies continue to bring about a loss in capacity, flows drop off accordingly and congestion persists. This trend continues until a rebalancing of the capacity-demand relationship takes place. The operational capacity approaches the actual capacity, and stable flow with no congestion is restored (Condition 3).

A review of traffic on several freeways under varying congestion conditions in California indicated that freeway efficiency was reduced in some cases by as much as 50 percent as congestion set in, falling from a free-flow rate of 1,800 to 2,000 vehicles per hour per lane (vphl) to, in the most extreme case, a flow of approximately 1,000 vphl under stop-and-go operation (Roper, unpublished data). Traffic flow losses in the 25 to 30 percent range were not uncommon (*6*). If the conditions leading to gridlock could be avoided (i.e., the capacity-demand balance could be maintained), congestion would be minimized, and operational capacity caused by unstable flow would not materialize. In effect, the traffic flow/capacity loss would be preserved, or added back into the system, to serve greater traffic demands.

A typical freeway management response to prevent gridlock has been to institute ramp metering to regulate the entry of vehicles onto the facility. Ramp metering has been proven to be a very successful strategy and has been used to maintain freeway operations in the balanced portion of the density-flow curve. The primary reason behind the success of ramp metering is the dispersion of vehicle platoons entering the freeway. However, when freeway-to-freeway connectors remain uncontrolled, large traffic volumes have access to the freeway. Consequently, during peak travel periods, the freeway facility can again enter into the unbalanced portion of the density-flow curve.

Freeway connectors usually accommodate higher traffic volumes compared with typical freeway on-ramps; however, their basic operational characteristics are very similar. Both provide access to the freeway facility and usually have some amount of queue storage capability. As such, freeway connectors are capable of being metered similar to typical freeway on-ramps. There has been reluctance in certain areas to meter freeway-to-freeway connectors, largely because of difficulty in developing a constituency of supporters. Minneapolis, San Diego, Seattle, and Los Angeles have shown that connector metering can be both feasible and successful.

Assuming that both typical on-ramps and freeway connectors can be metered, the only input that remains uncontrolled is the freeway mainline. By metering the mainline to limit the number of vehicles that can be accommodated optimally given the downstream capacity and ramp volumes, travel delays traditionally incurred when vehicles are maneuvering into the heavily traveled freeway section may be eliminated. It is important to discern whether this mainline metering hypothesis can provide additional benefits over and above typical ramp metering. Because of the uncertainty and expense of field experimentation, traffic flow was modeled through computer simulation using the INTRAS computer simulation model. A discussion of the simulation model, study area network, and research methodology and results is presented next.

Simulation Model

The INTRAS simulation model was written in 1977 by KLD Associates for the FHWA. It was selected as the analysis tool for this research because its car-following algorithms provide for a realistic simulation of traffic operations on an actual freeway. INTRAS is a microscopic model that simulates the flow of individual vehicles, as opposed to the macroscopic model that simulates the flow of a group of vehicles. On freeways with traffic demand below capacity, traffic flow is smooth and can be modeled reasonably well with the general parameters of a macroscopic model. However, in congested flow, traffic behavior becomes more complex. Because this research focuses on freeway conditions under congested flow, it is important that the vehicular behavior be modeled as accurately as possible. For these reasons, the INTRAS microscopic model was selected. For specific details of the INTRAS simulation model, consult the manuals cited in Reference *(7)*.

Study Area Network

A simple freeway network was established to evaluate appropriately the impacts associated with mainline metering. The network, illustrated in Figure 2, consisted of a three-lane freeway approximately 5.6 km (3.5 mi) in length, with one on-ramp located in the middle of the network. It is recognized that typical freeway segments will also have off-ramps and, in many areas, on-ramps may be located within a distance shorter than 2.8 km (1.75 mi). However, if it is found that mainline metering can provide improved traffic operations within this simple freeway network, the mainline metering strategy may be appropriate for a more typical freeway section with several on- and off-ramps. Conversely, if within the simple freeway network it cannot be shown that mainline metering provides any additional freeway traffic flow benefits, it will not be necessary to extend the research to a more typical freeway condition.

For simulation purposes, the freeway was divided into eight segments of 610 m (2,000 ft) each. Free-flow speed on the mainline was assumed to be 104.7 km/hr (65 mph), whereas free-flow speed for the on-ramp was assumed to be 88.6 km/hr (55 mph). The one-lane on-ramp also contained a 152.5-m (500-ft) auxiliary lane to facilitate vehicles merging from the on-ramp onto the freeway mainline. Although this freeway network is somewhat idealized, it is felt that the qualitative and quantitative results obtained from the simulation are analogous to a typical nonbottleneck freeway condition.

Research Methodology

The mainline metering evaluation was based on a variety of mainline volume and on-ramp control conditions. Previous experience has shown that the freeway mainline operates very well when mainline volumes are lower than 1,800 vphl. Consequently, mainline service volumes lower than 1,800 vphl were not evaluated. Specific mainline service volume rates analyzed included 1,800, 1,850, 1,900, and 1,950 vphl. Freeway lane capacity was defined as 2,000 vphl. Mainline volumes of 2,000 vphl were not analyzed because of limitations in the simulation model when analyzing service volumes equivalent to the capacity of a freeway lane. The vehicular demand on the on-ramp was kept constant at 1,200 vphl. However, the rate at which this on-ramp demand could access the freeway was simulated for the following conditions: no-control; ramp metering at 3 sec; ramp metering at 4 sec; and ramp metering at 5 sec. Ramp metering rates greater than 5 sec were not simulated because as the metering rate becomes more restrictive, the length of the on-ramp queue increases and can extend back to the arterial street, drawing objections from local jurisdictions.

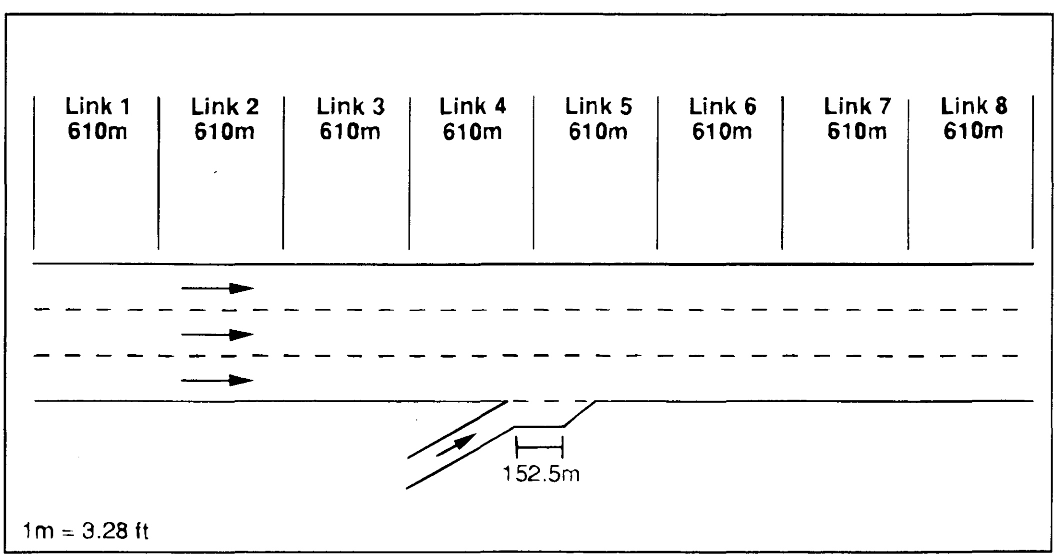

FIGURE 2 Study area network.

Because this evaluation was applied to an idealized freeway network and not actual field conditions, a simulation model calibration was not performed. For each mainline service volume condition, simulations were first performed for a base case assuming no form of control on either the on-ramp or mainline. Simulations were then performed using on-ramp metering rates of 3, 4, and 5 sec. Mainline metering was then simulated and evaluated for each of the three ramp metering conditions. In general, the mainline was metered at approximately 50 to 150 vphl less than the service volume demand. For example, if the service volume demand was 1,950 vphl, mainline metering was instituted to feed the downstream freeway at a rate of 1,900 or 1,800 vphl. Freeway conditions were simulated for a 30-min time period. Measures of effectiveness used to compare the results of these simulations included downstream vehicle throughput and downstream and overall speed.

It should be pointed out that this evaluation assumed that there would be no diversion as a result of either ramp or mainline metering. In actuality, there may be some diversion caused by both ramp and mainline metering, although to what extent is hard to predict. The purpose of this analysis is to determine the effect of mainline metering assuming the same level of demand (i.e., no diversion to local streets). If the simulation indicates that overall travel time is increased through the project area, then there is a strong likelihood that diversion would occur. On the other hand, if the simulation shows that overall travel time is reduced through mainline metering, then the propensity for diversion could be minimal. To appropriately evaluate the merits of mainline metering, the freeway demand is kept constant both with and without the on-ramp and mainline control strategies.

RESULTS

Vehicular Throughput

Figures 3 through 6 depict histograms of downstream vehicle throughput for the various combinations of mainline service volumes and on-ramp and mainline metering rates. It is important to realize that the combination of the mainline and on-ramp demands results in a total hourly demand of 6,600 to 7,050 vehicles downstream of the study area network. In addition, because traffic operations were simulated for a 30-min time period, the maximum downstream vehicular demand would range from 3,300 to 3,525 vehicles.

Figure 3 illustrates that for a mainline service volume of 1,800 vphl, the downstream vehicular throughput remains relatively unchanged for each of the control strategies simulated. Given that there are sufficient gaps in the mainline traffic stream for vehicles merging onto the freeway, implementation of ramp metering does not increase the downstream mainline throughput compared with the no-control scenario. Implementation of mainline metering results in slightly lower downstream traffic volumes compared with the ramp-meter-alone scenario. This result was expected, given that the network was able to effectively handle the ramp and mainline demands under the no-control scenario. With a service volume of 1,800 vphl, mainline metering would only serve to slow down vehicles, causing a reduction in downstream throughput.

Downstream throughput volumes for a mainline service volume of 1,850 vphl are shown in Figure 4. Noteworthy differences from the above results occur for the 5 sec ramp-meter-alone scenario and

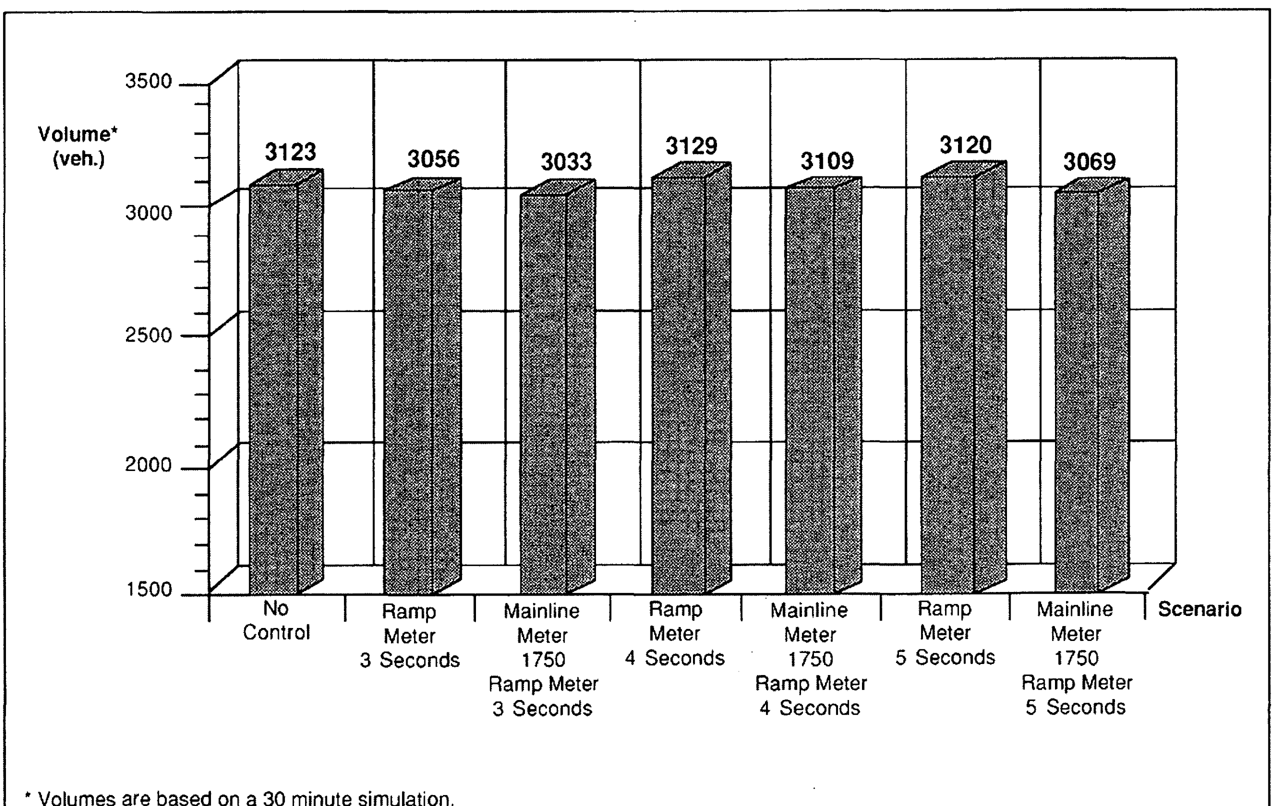

FIGURE 3 Downstream vehicle throughput for mainline service volume = 1,800 vphl.

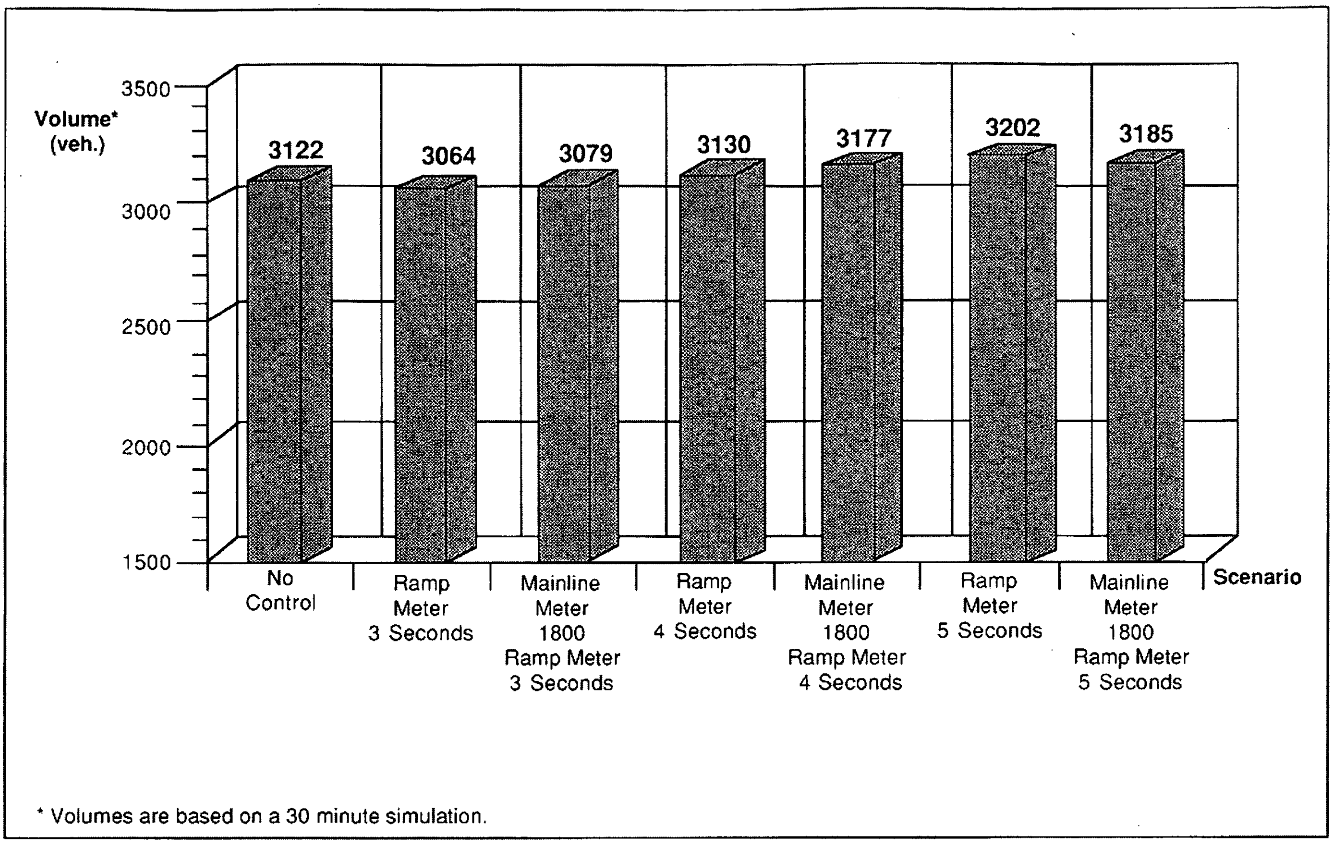

FIGURE 4 **Downstream vehicle throughput for mainline service volume = 1,850 vphl.**

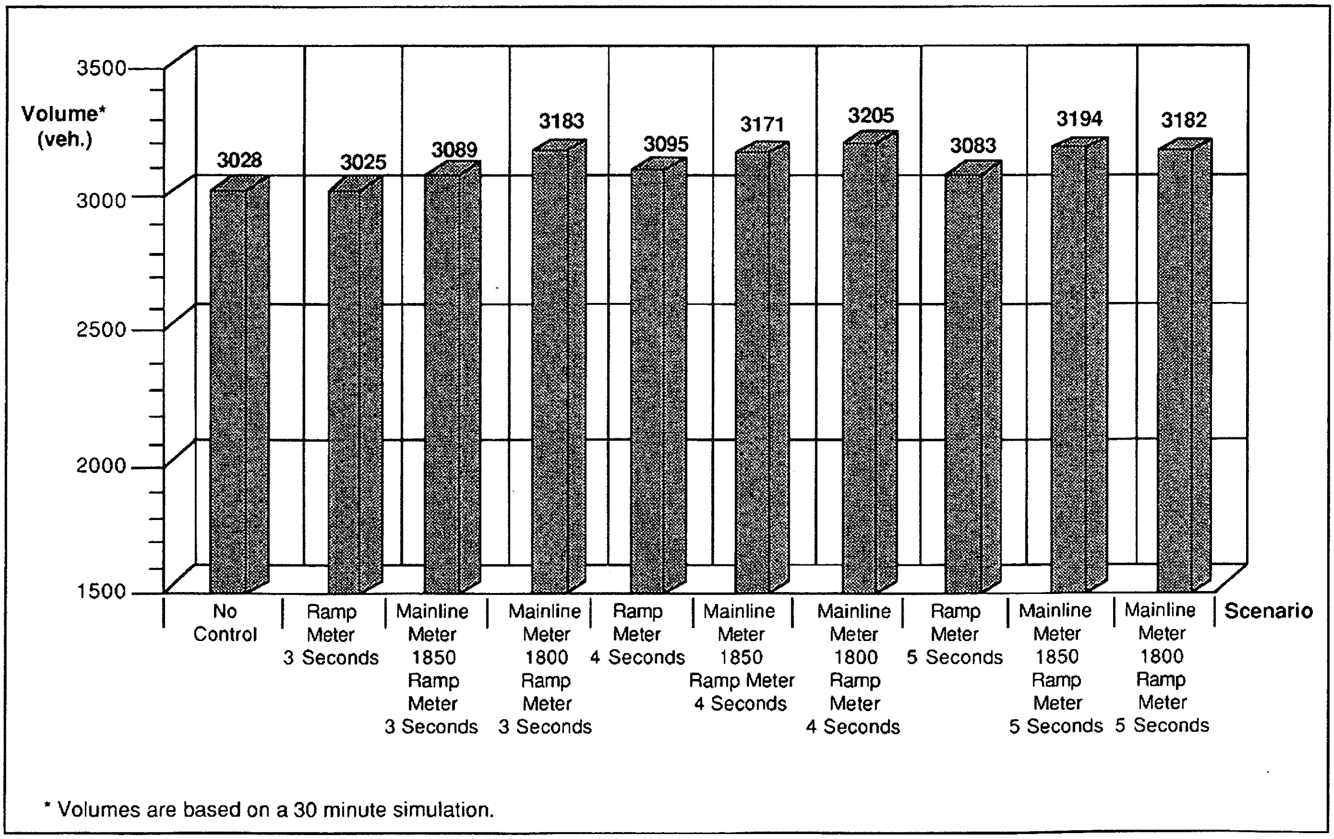

FIGURE 5 **Downstream vehicle throughput for mainline service volume = 1,900 vphl.**

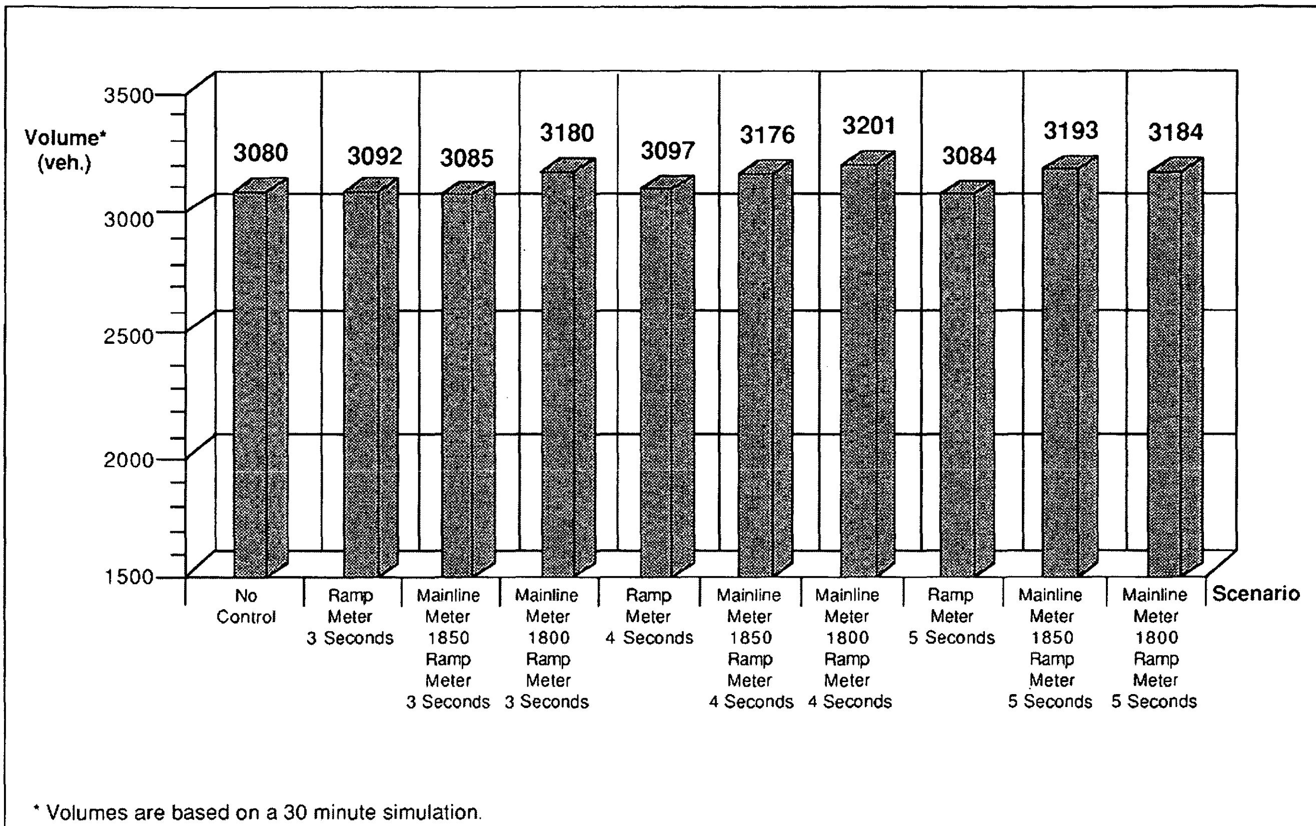

FIGURE 6 Downstream vehicle throughput for mainline service volume = 1,950 vphl.

the combined 4- and 5-sec ramp metering with mainline metering scenarios. These scenarios, which are the last three entries of Figure 4, resulted in an increase (approximately 2.5 percent) in downstream throughput compared with the no-control scenario.

Figures 5 and 6 present the downstream traffic volume results for mainline service volumes of 1,900 and 1,950 vphl, respectively. A review of the ramp-meter-alone scenario indicates the downstream traffic volumes generally increased, in some cases up to 3 or 4 percent, compared with the no-control scenarios. It appears that uncontrolled on-ramp traffic can cause a slight reduction in the downstream traffic volume because of the increase in mainline demand. Appropriately regulating on-ramp demand appears to eliminate the platooning of entering vehicles that can cause the reduction in downstream mainline volumes. When mainline metering is combined with on-ramp metering, the downstream traffic volume appears to increase an additional 3 percent compared with the ramp-meter-only scenarios.

Based on these results, it appears, for the nonbottleneck condition, that as freeway traffic volumes approach the capacity of the facility, mainline metering can increase downstream vehicular throughput above what ramp metering alone can accomplish.

Average Travel Speed

The average speed for each traffic control scenario and mainline service volume are indicated in Figures 7 through 10. In each figure, average speed downstream of the mainline meter and average speed for the network (which includes vehicles entering from the on-ramp and those upstream of the mainline meter) are indicated for each control strategy. For the no-control and ramp-meter-alone scenarios, the average speeds downstream of the mainline meter are indicated for comparative purposes and reflect the average speed downstream of where the mainline meter would have been.

Figures 7 through 10 indicate that for the ramp-meter-alone scenarios, the network speed and speed downstream of the mainline meter increase slightly as the ramp metering rate becomes more restrictive. With the implementation of mainline metering, the speeds downstream of the mainline meter are approximately 10 percent higher for the combined mainline and ramp meter scenarios when compared with the ramp-meter-alone scenarios. For these same scenarios, the overall network travel speeds are approximately the same or, in some cases, higher. The previous results appear to indicate that mainline metering can increase freeway speed downstream of the mainline meter, and the delays incurred upstream of the metering point do not result in any overall travel time increases for the nonbottleneck condition.

Also noteworthy is that as mainline service volumes increase, mainline metering offers larger speed increases downstream of the metering point compared with the no-control and ramp-meter-alone scenarios. These increases, illustrated in Table 1, are accomplished without increasing overall travel time.

Summary of Results

The purpose of the simulation was to determine whether there are any freeway operational benefits, above those achieved through ramp metering, resulting from metering the freeway mainline for

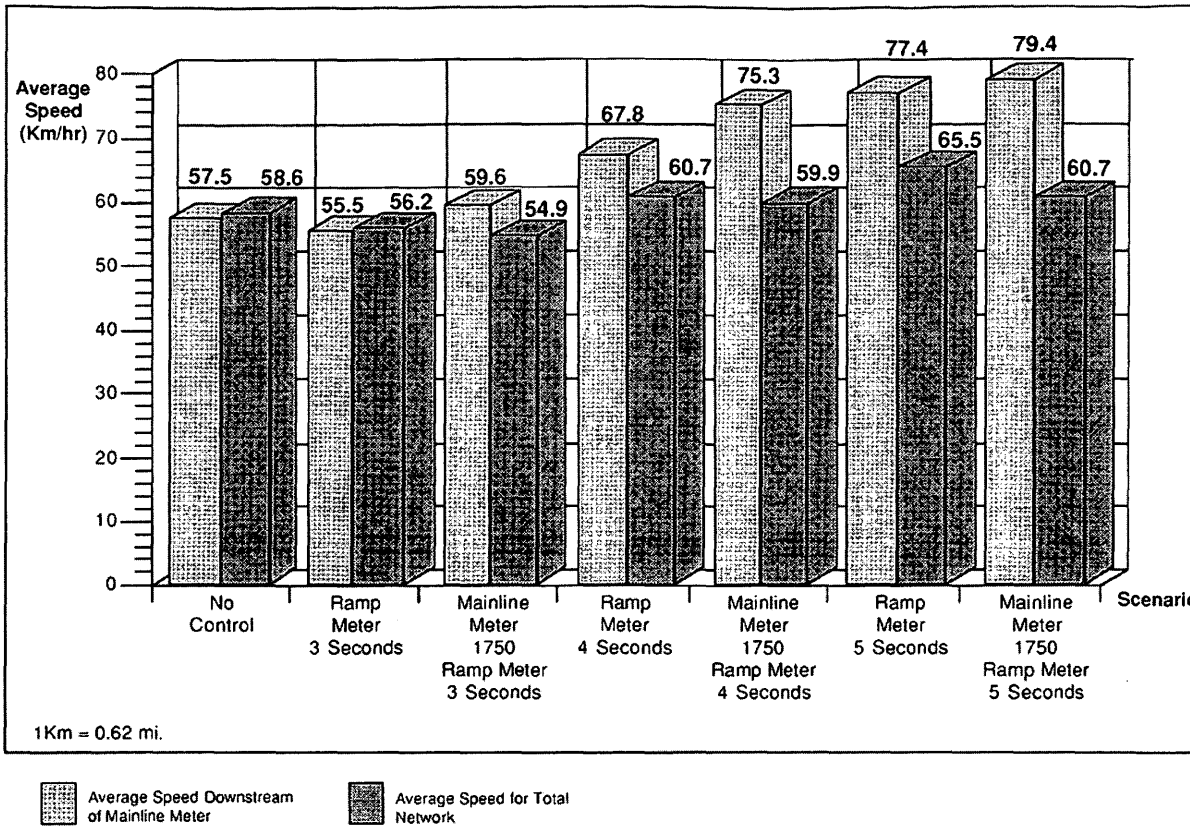

FIGURE 7 Average speed for mainline service volume = 1,800 vphl.

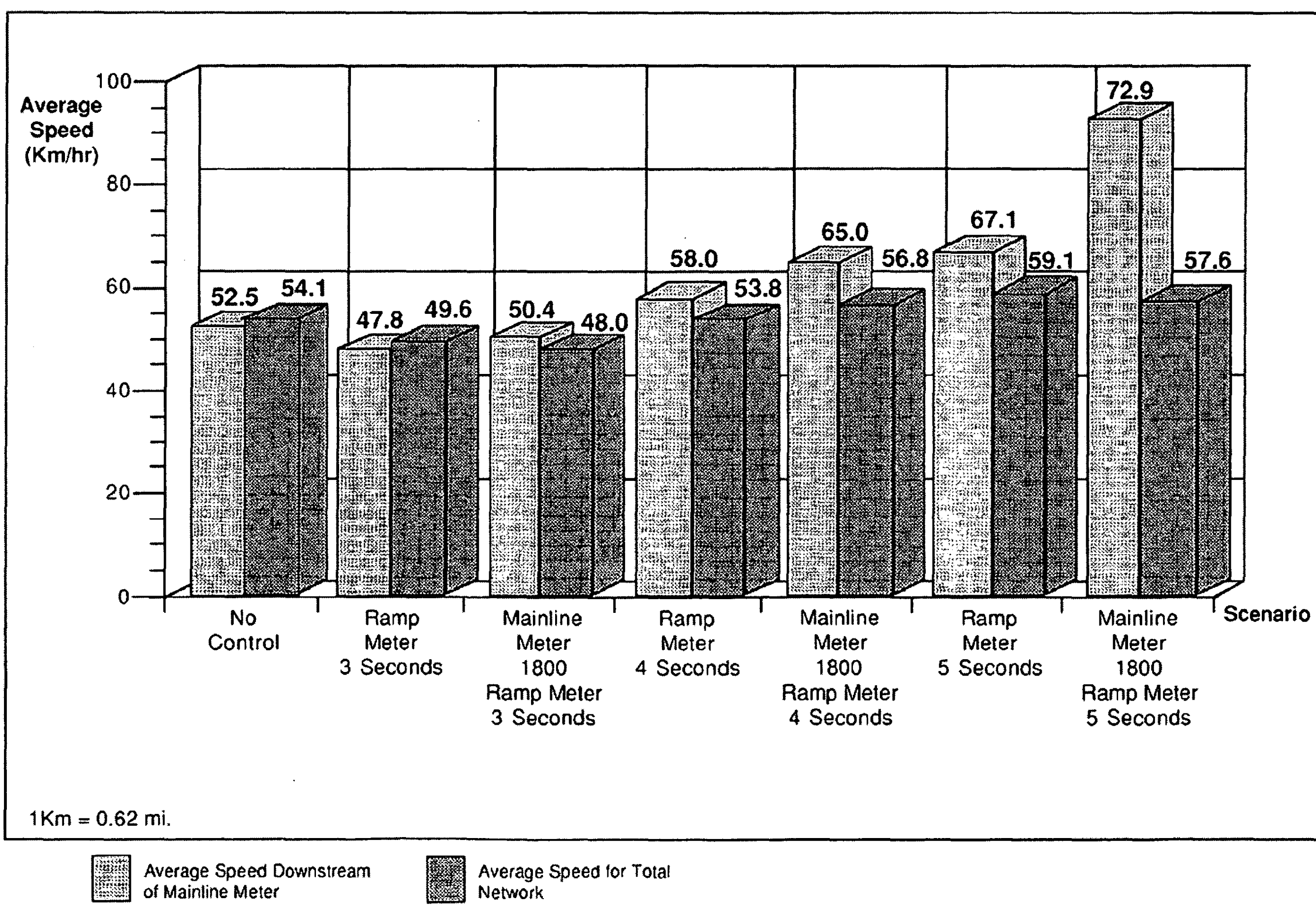

FIGURE 8 Average speed for mainline service volume = 1,850 vphl.

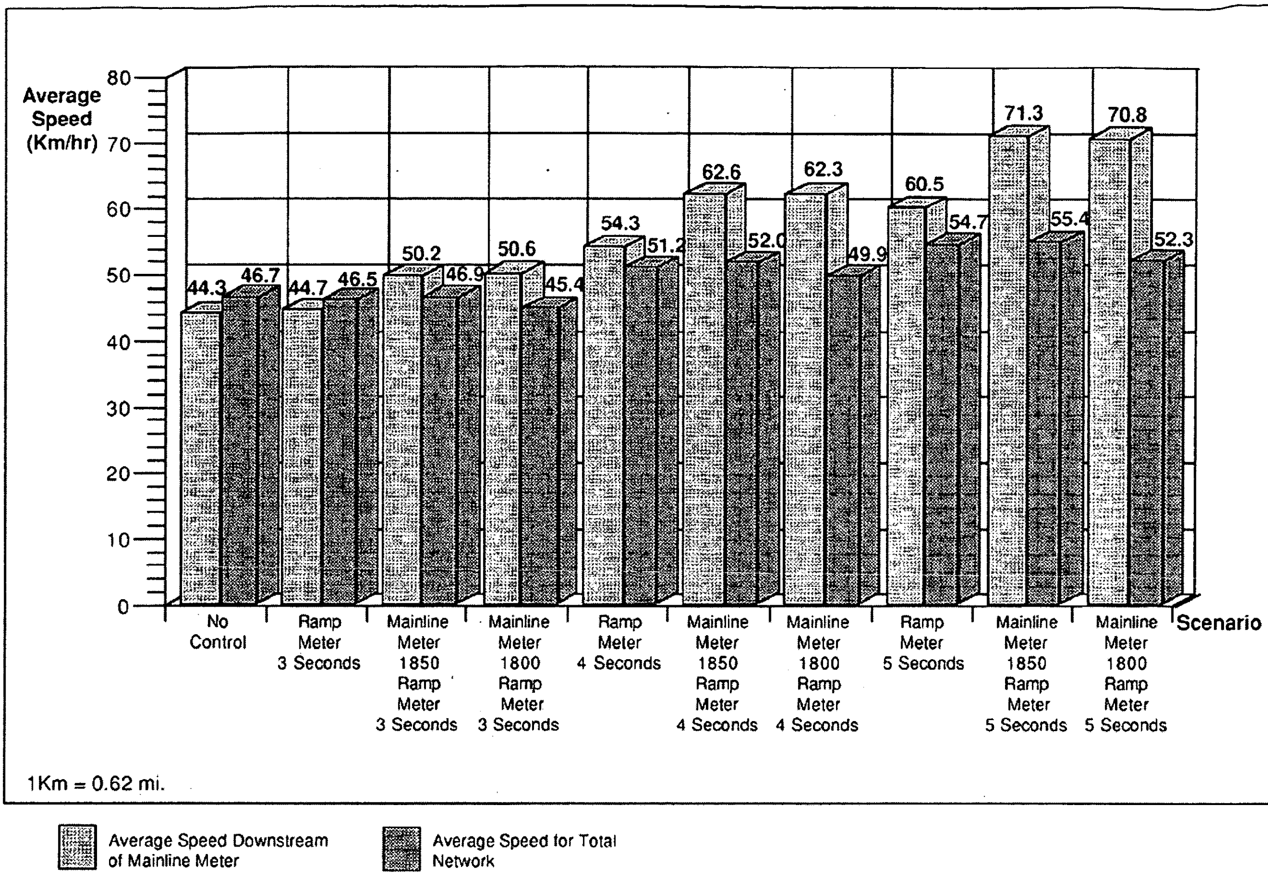

FIGURE 9 Average speed for mainline service volume = 1,900 vphl.

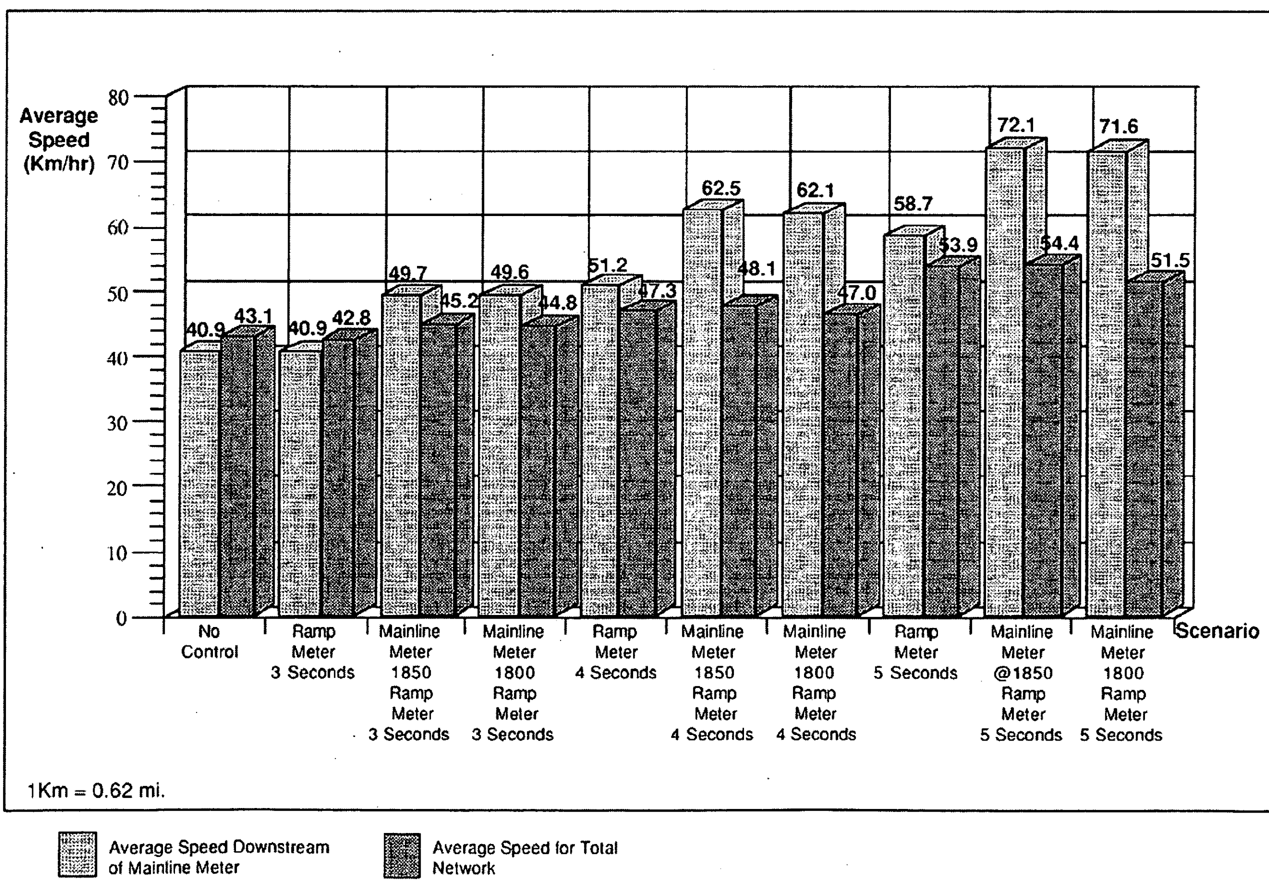

FIGURE 10 Average speed for mainline service volume = 1,950 vphl.

TABLE 1 Percent Increase in Freeway Speed Downstream of Mainline Meter*

Scenario	Mainline Service Volume (vphpl) 1,900	1,950
Ramp Meter 4 Seconds		
Mainline Meter @ 1,850 vphpl	15%	22%
Mainline Meter @ 1,850 vphpl	15%	21%
Ramp Meter 5 Seconds		
Mainline Meter @ 1,850 vphpl	18%	23%
Mainline Meter @ 1,800 vphpl	17%	22%

** Compared to Ramp Metering alone Scenario*
(vphpl) = vehicles per hour per lane

the nonbottleneck condition. Several observations drawn from the previous results include the following:

- As the freeway mainline volume increases, ramp metering appears to increase the downstream vehicular throughput by approximately 2 to 4 percent. This result is consistent with existing experiences with ramp metering to date.
- Ramp metering appears to increase the freeway speed and the average speed for the entire freeway network compared with the no-control scenario. In addition, the more restrictive the metering rate, the better level of operation on the freeway (in terms of higher speeds and lower travel times).
- Combining mainline metering with ramp metering resulted in the same or, in several cases, slightly higher downstream vehicular throughput compared with the no-control and ramp-meter-alone scenarios.
- As mainline service volumes increase, the freeway speed for the ramp-meter-alone scenario decreases. The addition of mainline metering provides much improved freeway conditions downstream of the mainline meter. This improvement is balanced by the added travel time incurred upstream of the mainline meter.
- When mainline metering is combined with ramp metering, the average freeway speed for the total network increases compared with the ramp-meter-alone scenarios. Figures 8 and 9 indicate that this speed increase can be as high as 8 to 11 km/hr (5 to 7 mph).
- Vehicles originating from on-ramps downstream of the mainline meter are provided better freeway conditions compared with the no-control and ramp-meter-alone scenarios. Consequently, vehicles originating from these downstream on-ramps experience lower freeway travel times.

IMPLICATIONS OF RESULTS

These results appear to indicate that mainline metering can provide improved freeway operations downstream of the metering point compared with ramp metering alone. For mainline service volumes of 1,950 vphl, the average freeway speed downstream of the mainline meter was 22 percent higher than the ramp-meter-alone scenario. But, most important, the simulation indicates that this can be accomplished while decreasing freeway travel time. This is an important observation, considering that one of the concerns regarding mainline metering has been the perception of additional delay incurred by vehicles waiting in a mainline queue upstream of the mainline meter. From these results, it appears that this delay is balanced by improved freeway operations downstream of the mainline meter. Based on metering experiences in San Diego (*8*), commuters are willing to wait in a queue (in San Diego's case, it is more of a rolling queue) provided they perceive an improvement in their trip farther downstream.

The results are also important when considering the equity issue. One of the historical arguments against ramp metering is that vehicles originating from entry points closer to their destination incur a greater travel time delay than vehicles originating farther out in the suburbs. Based on this research effort, it appears that mainline metering may not increase the overall travel time through the freeway network, and may be used to distribute more equitably the delay incurred by vehicles ingressing the freeway. For example, consider the morning commute of a line-haul freeway approaching the outskirts of a metropolitan area. A mainline meter may eliminate the need to meter on-ramps upstream of the mainline meter location. The delay experienced by commuters using this particular freeway could be distributed equitably between the mainline meter and metered on-ramps downstream of the mainline meter. In addition, mainline metering can promote ridesharing and HOV travel time savings. Similar to HOV operations at the Bay Bridge, HOVs could gain travel time benefits over single occupant vehicles via HOV bypass lanes upstream of the metering point.

This research appears to indicate that, depending on the goals and objectives of the freeway operating agency and given the right conditions, mainline metering is an appropriate freeway management tool.

REFERENCES

1. Lerner-Lam, E. *Mobility Facts.* The Institute of Transportation Engineers, Washington, D.C., 1992.
2. Jacobson, E. L., and J. Landsman. Case Studies of Freeway to Freeway Ramp and Mainline Metering in the U.S., and Suggested Policies for Washington State. Presented at 73rd Annual Meeting of the Transportation Research Board, Washington, D.C., 1994.
3. Harrison, J. E. Hampton Roads Bridge Tunnel Traffic Control and Surveillance System. Presented at 66th Annual Meeting of the Transportation Research Board, Washington, D.C., 1987.
4. Carter, E. C., and R. C. Loutzenheiser. *Study of Traffic Flow on a Restricted Facility.* Report FHWA-MD-R-77-9. FHWA, U.S. Department of Transportation, 1977.
5. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
6. *Traffic Engineering Handbook,* 4th ed. Institute of Transportation Engineers, Washington, D.C. 1992.
7. KLD Associates. *Development and Testing of INTRAS: A Microscopic Freeway Simulation Model,* Vols. 1,2,3, and 4. Federal Highway Administration, Washington, D.C., 1977.
8. Haboian, K. A. *Freeway Management Strategies.* Parsons Brinckerhoff Inc., New York, 1993.

Publication of this paper sponsored by Committee on Freeway Operations.