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Ramp Metering Status in North America

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Final Report
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RAMP METERING STATUS IN NORTH AMERICA - Final Report

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INTRODUCTION

Webster's New Collegiate Dictionary defines the verb "meter" as: "to supply in a measured or regulated amount". Ramp meters are traffic signals on freeway entrance ramps that supply traffic to the freeway in a measured or regulated amount. In the "measured" mode, meters can be operated to discharge traffic at a measured rate thus maintaining the capacity of a downstream bottleneck. As long as mainline demand plus ramp traffic flow does not exceed capacity, throughput is maximized, speeds remain more uniform and congestion related accidents are reduced. Ramp meters can also be operated to regulate ramp traffic to break up platoons of vehicles that have been released from nearby signalized intersections. The mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time. On the other hand, when groups of vehicles attempt to force their way into traffic it creates turbulence that causes mainline flow to breakdown. Reduced turbulence in the merge zones also leads to reduced sideswipe and rear-end type accidents that are associated with stop-and-go, erratic traffic flow.

Ramp metering is not a new traffic management concept. The first metered ramp, as we know it today, was installed in Chicago on the Eisenhower Expressway in 1963. This first application, however, was preceded by successful tests of the effectiveness of metering traffic entering New York tunnels and ramp closure studies in Detroit. It is interesting to note that the initial Chicago study featured a police officer, stationed on the entrance ramp, who stopped traffic and released vehicles one at a time at a rate determined from a pilot detection program.[1] In Los Angeles ramp metering began in 1968. That system has been expanded continually until there are now over 900 meters in operation in the L.A. metropolitan area - the largest system in the country. Currently ramp meters are in operation in 20 metropolitan areas in North America (Figure 1). These metering systems vary from a fixed time operation at a single ramp to computerized control of every ramp along many miles of a freeway. One measure of the effectiveness of metering, perhaps, is the fact that every existing system has been or is proposed to be expanded.

The objective of this paper is to provide an initial resource for those wishing to explore the feasibility of ramp metering in their areas. The paper is divided into three sections. The first presents a sample of ramp metering applications in several cities and describes the benefits that have been reported. The second section addresses various factors that should be

RAMP METERING SYSTEMS

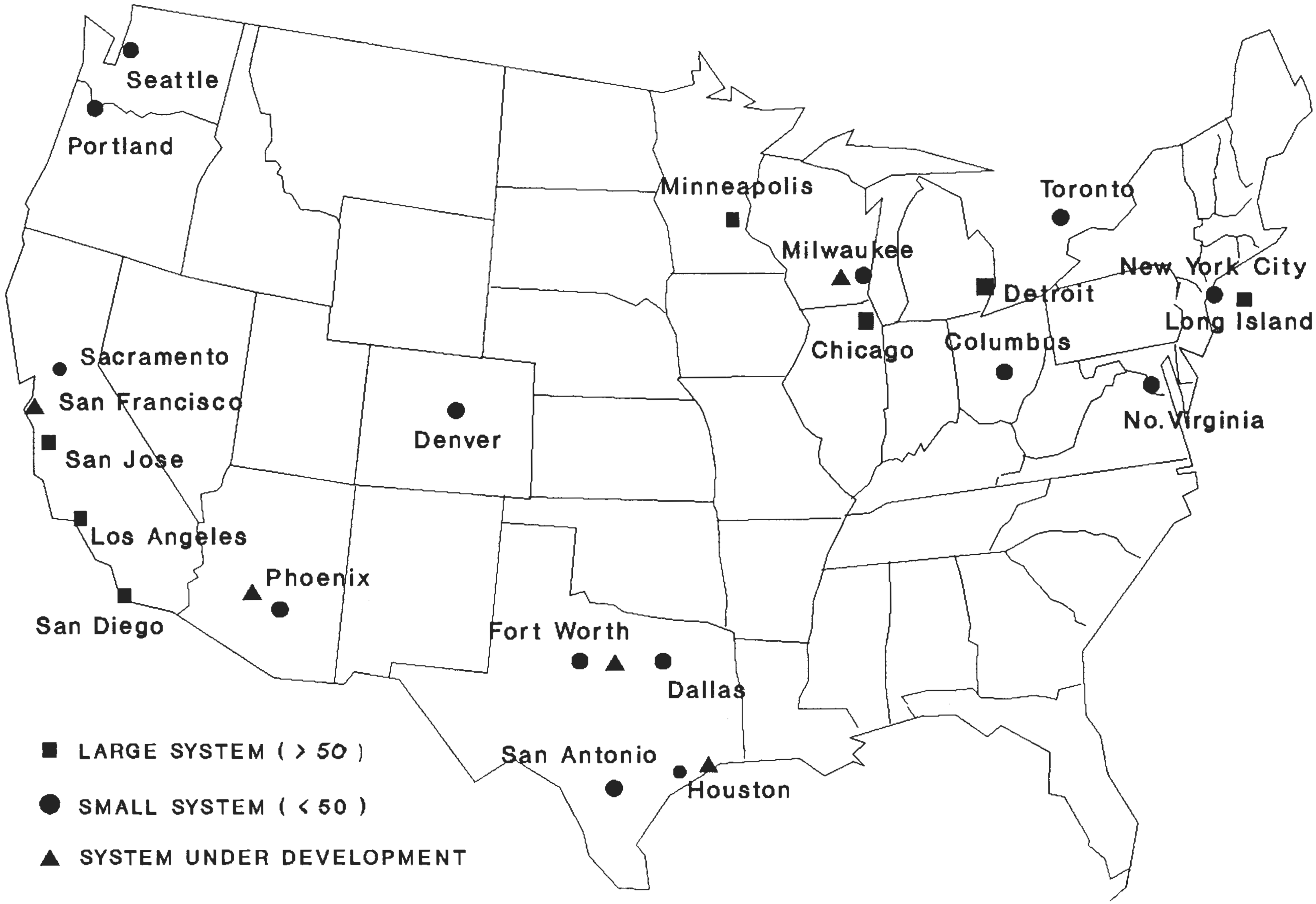

FIGURE 1

considered and some of the capabilities and limitations of ramp metering. In the third, guidelines for the implementation of ramp metering are identified. An overview of the status of ramp metering in North America and a bibliography are also included.

RAMP METERING CASE STUDIES

The abbreviated case studies presented here are just a few examples of effective ramp metering operations. The statistics presented are not consistent from city to city as there is no uniform evaluation criteria for metering and the measures of effectiveness (MOE) vary depending on the objectives of the system. Complicating the matter, many ramp metering installations are implemented at the same time as other freeway improvements such as increased capacity, high occupancy vehicle (HOV) lanes, driver information systems, and incident management programs. In these cases, it is not always possible to evaluate the individual components of the larger projects. The conditions of the evaluations of these case studies are noted in the discussion of each.

Portland, Oregon

The first ramp meters in the Pacific Northwest were installed along a six mile section of I-5 in Portland in January 1981. The meters are operated by the Oregon Department of Transportation. This freeway is the major north/south link, and is an important commuter route through the metropolitan area. The system consists of 16 metered ramps between downtown Portland and the Washington state line. Nine of the meters operate in the northbound direction during the PM peak and seven control southbound entrances during the AM peak. The meters operate in a fixed time mode.

Prior to metering, it was common along this section of I-5 for platoons of vehicles to merge onto the freeway and aggravate the slow-down of congested traffic. The northbound PM peak hour average speed was 16 MPH. Fourteen months after installation, the average speed for the same time period was 41 MPH. Travel time was reduced from 23 minutes (but highly variable) to about 9 minutes. Premetered conditions in the southbound AM peak were much less severe and hence the improvements were smaller. Average speeds increased from 40 to 43 MPH resulting in only slight reductions in southbound travel times.

Additional benefits that were evaluated for the PM peak period included fuel savings and a before and after accident study. It was estimated that fuel consumption, including the additional consumption caused by ramp delay, was reduced by 540 gallons of gasoline per weekday. There was also a reduction in rear-end and side swipe accidents. Overall, there was a 43% reduction in peak period traffic accidents.[2]

Minneapolis/St. Paul, Minnesota
The Twin Cities Metropolitan Area Freeway Management System is composed of several systems and sub-systems that have been implemented over a 20 year period by the Minnesota Department of Transportation. The first two fixed time meters were installed in 1970 on southbound I-35E north of downtown St. Paul. In November 1971, these were upgraded to operate on a local traffic responsive basis and 4 additional meters were activated. This five mile section of I-35E has been evaluated periodically since the meters were installed. The most recent study shows, that after 14 years of operation, average peak hour speeds remain 16% higher (from 37 to 43 mph) than before metering. Peak period volumes have increased 25% over the same time period due to increased demand. The average number of peak period accidents decreased 24% and the peak period accident rate decreased 38%.

In 1974 a freeway management project was activated on a seventeen mile section of I-35W from downtown Minneapolis to the southern suburbs. In addition to 39 ramp meters, the system included 16 closed circuit television (CCTV) cameras, 5 variable message signs (VMS), a 6000 foot zone of highway advisory radio (HAR), 380 vehicle detectors, and a computer control monitor located at the Minneapolis Traffic Management Center. This project also included extensive "freeway flyer" bus service, and eleven ramp meter bypass ramps for HOV's. An evaluation of this project after 10 years of operation shows that average peak period freeway speeds increased from 34 to 46 MPH (35%). Over the same 10 year span, peak period volume increased 32%, the average number of peak period accidents declined 27%, and the peak period accident rate declined 38%.[3]

Additional ramp metering projects were activated in 1980 and 1985 and additional projects are now in the design and construction phases. The long range plan is to extend the traffic management program over the entire Twin Cities freeway network as traffic conditions warrant. The success of the Twin Cities system has shown that the staged implementation of a comprehensive freeway management system on a segment-by-segment, freeway-by-freeway basis, over a long period of time, is an effective way of implementing an area wide program.

Seattle, Washington
In September 1981 the Washington State Department of Transportation (WSDOT) implemented metering on I-5 north of the Seattle CBD. Currently the system which is named FLOW (not an acronym), includes 17 southbound ramps that are metered during the AM peak, and five northbound ramps metered during the PM peak. A recently completed evaluation shows that between 1981 and 1987, mainline volumes during the peak traffic periods increased 86% northbound and 62% southbound. Before the installation of metering, the travel time on a specific 6.9 mile course was measured at 22 minutes. In 1987 the travel time for

the same course was measured at 11.5 minutes. Over the same six year time period, the accident rate decreased by 39%.[4]

Another, somewhat unique, application of metering was implemented in Seattle on SR-520 in 1986. While diversion caused by metering is often controversial, one of the objectives of metering SR-520 was to reduce commuter diversion through a residential neighborhood. The meters were installed on the two eastbound ramps on SR-520 between I-5 and Lake Washington. One of these ramps, the Lake Washington Blvd. on-ramp, is the last entry onto SR-520 before the Evergreen Point Floating Bridge. Because there were no bottlenecks downstream of this ramp, traffic would normally flow freely on the bridge and beyond. Motorists, especially commuters from downtown Seattle, were using residential streets to reach the Lake Washington Blvd. on-ramp to avoid congestion on SR-520. This on-ramp, however, was a major contributor to congestion on SR-520 because of the high entering volumes. By metering the ramp, it was anticipated that traffic diverting through the adjacent neighborhood from downtown would be discouraged by the delay caused by the meter and would instead use the Montlake Blvd. on-ramp which was also metered at the same time. A HOV bypass lane was also installed at the Montlake Blvd. on-ramp. Two other objectives of this project were to improve flow on SR-520 and to encourage increased transit use and carpooling.

An evaluation of this two ramp meter "system" after four months of operation showed there was a 6.5% increase in mainline peak period volume, a 43% decrease in the volume on the Lake Washington Blvd. on-ramp, an 18% increase the volume on the Montlake Blvd. on-ramp, and a 44% increase in HOV's using the Montlake Blvd. on-ramp. Another indication of the effectiveness of the combination of the HOV bypass and the improved SR-520 flow is a decrease of 3 minutes in METRO bus travel times for buses traveling from downtown to the east and a 4 minute decrease for buses traveling from University District to the east. The reliability of the bus travel times also improved and METRO adjusted the schedules for these routes accordingly.

<u>Denver, Colorado</u>
The Colorado Department of Highways activated a pilot project to demonstrate the effectiveness of ramp metering on a section of northbound I-25 in March 1981. The initial system consisted of five local traffic responsive metered ramps operated during the AM peak on a 2.9 mile section of I-25 south of the city. Periodic after evaluations revealed significant benefits. An 18 month after study showed that average peak period driving speed increased 57% and average travel times decreased 37%. Stop and go conditions on the section were generally eliminated and the incidence of rear-end and side-swipe accidents declined 5%.

The success of the pilot project led to expansion of the system. In 1984 a central computer was installed and a System Coordination Plan implemented which permits central monitoring and control of all meters. Additional locations were added between 1985 and 1989. Currently, there are 26 metered locations and two more will be added in 1990. In late 1988 and early 1989 a comprehensive evaluation of the original metered section was conducted. A number of changes occurred between 1981 and 1989, the most significant of which was the completion of a new freeway, C-470, which permitted more direct access to I-25 from the southwest area and generated higher demand for I-25. Volumes during the 2 hour AM peak period increased from 6200 vph in 1981 to 7350 vph in 1989 (on 3 lanes). Speeds measured in late 1988 decreased from the original evaluation, but remained higher than the speeds before metering was implemented (43 mph before, 53 mph in 1981, and 50 mph in late 1988). The number of accidents during the AM peak period did not increase between the original evaluation and 1989 which means the accident rate decreased significantly because of the increase in volume. Rear end and side swipe type accidents decreased by 50% during metered periods.

An interesting unplanned "evaluation" of the system occurred in the Spring of 1987. To accommodate daylight savings time, all of the individual ramp controllers were adjusted one hour ahead. Unfortunately, the central computer clock was overlooked. The central computer overrode the local controllers and metering began an hour late. Traffic was the worst it had been in years. This oversight did have a bright side for the DOH, the media has been even more supportive of metering since this incident.[6]

Detroit, Michigan

Ramp metering is an important aspect of the Michigan Department of Transportation's (MDOT) Surveillance Control and Driver Information (SCANDI) System in Detroit. The SCANDI metering operation began in November 1982 with six ramps on the eastbound Ford Freeway (I-94). Nineteen more ramps were added on I-94 in January 1984 and three in November 1985. An evaluation performed by Michigan State University for MDOT determined that ramp metering increased speeds on I-94 by about 8%. At the same time, the typical peak hour volume on the three eastbound lanes increased to 6400 vehicles per hour from an average of 5600 VPH before metering. In addition, the total number of accidents was reduced nearly 50% and injury accidents were down 71%. The evaluation done by Michigan State also showed that significant additional benefits could be achieved by metering the three freeway to freeway connectors on this section of I-94.[7]

Austin, Texas

In Austin, the Texas State Department of Highways and Public Transportation implemented traffic responsive meters at 3 ramps along a 2.6 mile segment of northbound I-35 for operation during the AM peak period. The section of freeway had two bottleneck locations that were reducing the quality of travel. One was a reduction from 3 to 2 lanes and the other was a high volume entrance ramp just downstream of the lane reduction. Metering resulted in an increased vehicle throughput of 7.9% and an increase in average peak period mainline speeds of 60% through the section. The meters were removed after the reconstruction of I-35 eliminated the lane drop in this section.[8]

Long Island, New York

At the other end of the spectrum from Austin is the INFORM (Information for Motorists) project on Long Island. The INFORM project covers a 40 mile long by 5 mile wide corridor at the center of which is the Long Island Expressway (LIE). Also included in the system is an east-west parkway, an east-west arterial and several crossing arterials and parkways, a total of 128 miles of roadways. System elements include 58 metered ramps on the LIE and the Northern State/Grand Central Parkway. Metering began at 6 ramps in Suffolk County in late 1988. Thirty of the meters are now operating, and all will become operational in 1989.

An analysis of the initial metered segment after 2 months of operation in the PM peak, shows a 20% decrease in mainline travel time (from 26 to 21 minutes) and a 16% increase in average speed (from 29 to 35 mph). Motorists entering at metered ramps also experienced an overall travel time reduction of 13.1% and an increase in average speed from 23 to 28 mph. The MOE's for this project include vehicle emissions. For this initial segment, the analysis indicates there was a 6.7% reduction in fuel consumption, 17.4% reduction in carbon monoxide emissions, 13.1% reduction in hydrocarbons, and 2.4% increase in nitrous oxide emissions. The latter is associated with the higher speeds. Initial observations of the effect of metering the four lane parkway on the INFORM project, indicates the benefits may be even greater than those achieved on wider freeways. Intuitively this makes sense because the impact of an unrestricted merge on only two lanes (in one direction) can be severe.[9] The INFORM project will be subjected to one of the most extensive evaluations ever conducted on a traffic management program which will add greatly to the state-of-the-knowledge as it becomes fully implemented.

San Diego, California

In San Diego, ramp metering was initiated in 1968. That system, installed and operated by the California Department of Transportation (Caltrans), now includes 81 metered ramps on 40 plus miles of freeway. No detailed evaluations of metering have been conducted on the San Diego system since the early installations, but sustained volumes of 2200 vph to 2400 vph, and occasionally even higher, are common on San Diego metered freeways. A noteworthy aspect of the program is the metering of four freeway-to-freeway connector ramps. Metering freeway-to-freeway connectors requires careful attention to storage space, advanced warning, and sight distance. If conditions allow, freeway connector metering can be just as safe and effective as other ramp meters.[10] Minneapolis successfully meters 12 freeway-to-freeway ramps, and both San Antonio and San Jose have a metered freeway-to-freeway interchange.

Summary of Ramp Metering Benefits

Metering entrance ramps significantly improves mainline traffic flow. These case study evaluations, as well as others, show metering consistently increases travel speeds and improves travel time reliability, both of which are measures of reduced stop-and-go, erratic flow. Metering helps smooth out peak demands which would otherwise cause the mainline flow to breakdown. A good case can be made from the data reported that metering actually increases the capacity of a freeway. The data from Minneapolis, San Diego, Seattle, Detroit and Denver shows mainline volumes well in excess of 2,000 vph per lane on metered sections, and sustained volumes in the range of 5% to 6% greater than premetered conditions. Improved traffic flow, particularly the reduction in stop-and-go conditions, also reduces vehicle emissions. Only for the INFORM project on Long Island has the reduction in emissions been calculated as part of a metering project evaluation.

The other direct benefit, but one that has not been fully quantified, is the reduction in accidents attributed to metering. The benefits of reducing accidents is much greater than the direct costs of an accident. To illustrate, assume an accident blocks one lane of three at the beginning of the peak period on a freeway with a 2 hour peak demand of 6000 vph. Studies show an accident blocking one of three lanes reduces capacity by 50%. A 20 minute blockage would cause 2100 vehicle-hours of delay, a queue almost 2 miles long, and take 2 1/2 hours to return to normal assuming there were no secondary accidents or incidents. Clearly the safety aspects of metering are a major benefit.

RAMP METERING CONSIDERATIONS

It is not the intent of this paper to "sell" metering. Ramp metering is not a cure-all for freeway traffic congestion, but properly designed and well managed ramp metering has proven to be an extremely cost effective strategy in reducing congestion. Metering is not appropriate for every location, however, and there are issues of design and operation that must be considered before implementing any ramp metering program.

Types of Ramp Metering Systems

The sophistication and extent of a ramp metering system should be based on the amount of improvement desired, existing traffic conditions, installation costs, and the continuing resource requirements that are necessary to operate and maintain the system effectively. The simplest form of control is a fixed time operation. It performs the basic functions of breaking up platoons into single-vehicle entries and setting an upper limit on the flow rates that enter the freeway. Presence and passage detectors may be installed on the ramp to actuate and terminate the metering cycles, but the metering rate is based on average traffic conditions at a particular ramp at a particular time. This type of operation provides the benefits associated with accident reductions, but is not as effective in regulating freeway volumes because there is no input about mainline traffic. Pretimed control can be implemented on any number of ramps, and is often implemented as an initial operating strategy until individual ramps can be incorporated into a traffic responsive system.

The next level of control, traffic responsive, establishes metering rates based on actual freeway conditions. The local traffic responsive approach utilizes detectors and a micro-processor to determine the mainline flow in the immediate vicinity of the ramp and the ramp demand to select an appropriate metering rate. Traffic responsive control also permits ramp metering to be used to help manage demand when incidents occur on the freeway, i.e. reduce the metering rate at ramps upstream of the incident and increase the rate at ramps downstream.

System control is a form of traffic responsive control but operates on the basis of total freeway conditions. Centralized computer controlled systems can handle numerous ramps in a traffic responsive scheme and feature multiple control programs and overrides. Control strategies can also be distributed among individual ramps. A significant feature of system control is interconnection that permits the metering rate at any ramp to be influenced by conditions at other locations. References **11** and **12** contain detailed descriptions of the types of metering controls.

System control need not be limited to the freeway and its ramps. The concept of integrated traffic control combines or coordinates freeway and surface street control systems to operate on the basis of corridor wide traffic conditions. The potential advantages of integrated control include reduced installation and operating costs, corridor wide surveillance, better motorist information, and quicker and coordinated use of all of the control elements (meters, signals, signs, etc.) in response to real time traffic conditions. The only existing integrated system in the U.S. is the INFORM project, but the concept is attracting considerable interest and several agencies are now actively pursuing the integration of freeway and signal control systems. The initial efforts are primarily aimed at incident situations where signal timing can be modified in response to freeway incidents. Work is also underway, however, on corridor wide surveillance and adaptive control strategies.

Metering Rates

Metering rates have definite upper and lower limits which do affect the feasibility of metering. The maximum discharge rate of a single metered lane is about 900 vehicles per hour. This is based on a minimum reasonable cycle length of 4 seconds (2.5 seconds of red, or red plus yellow, and 1.5 of green). The discharge rate can be increased by permitting two vehicles per green, but then the minimum cycle length should be increased to about 6 or 6.5 seconds. The maximum discharge rate, though, becomes 1000 to 1100 vph. Another technique employed at high volume ramps is to widen the ramp to 2 or more lanes at the meter and permit one or two vehicles per lane per green. These ramps are then transitioned back to one lane before merging with the freeway. Metering high volume ramps presents a number of problems and requires extensive analysis.

It has also been found that there is a practical minimum discharge rate as drivers simply will not wait more than about 15 seconds. At that point violations increase significantly. The most restrictive rate then is about 240 vph. It may take several weeks or even months to arrive at a final rate after metering is initiated and it is important to observe the operation closely.

Ramp Geometrics

Ramps should possess characteristics suitable for metering. The two primary considerations are the availability of storage space and adequate acceleration distance and merge area beyond the meter. Storage requirements can be estimated from the projected metering rate and the ramp traffic demand. An adjustment can also be made for shifts in demand that may occur as a result of metering. A number of techniques are employed to assure that nonfreeway bound traffic on local streets is not adversely impacted by ramp meter queues.

The most common technique used to increase storage space is to increase the number of lanes on the ramp before the meter. On new freeways, even where metering is not contemplated until some future date, provisions for adequate storage should be a design consideration. On existing freeways, restriping or reconstructing ramps to allow for two or more lanes is common. In Minneapolis, one loop ramp was widened to four lanes approaching the meters. The meters release vehicles from two lanes at a time, alternating between the right pair and the left pair. Downstream of the meter the vehicles merge into one lane before reaching the freeway. In Minneapolis it has become standard procedure to meter ramps only if two or more storage lanes can be provided.

Estimating shifts in demand requires judgement and should be based on site and traffic conditions. To estimate the storage requirements for new installations in Minneapolis, the staff uses a rule-of-thumb of 10% of the premetered peak hour volume. In other words, if there is storage for a 6 minute premetered peak volume, it should be adequate. If there is storage for a 3 minute peak, or 5% of the premetered volume, it may be adequate but additional analysis is necessary and mitigating measures may be required. If the storage length is not adequate for 5% of the premetered volume, mitigating measures are required or metering is not considered feasible. In San Diego, it has been observed that a 10% to 15% reduction in premetering peak hour ramp volumes is usually achievable without significant adverse impact.

In San Diego, storage is not limited to the ramp proper in most locations. There, a portion of the surface street approach is used to store vehicles, in one location as far as 2000 feet from the freeway. This arrangement may require modification of signal timing at nearby intersections and channelization to reduce the impact the ramp queue might have on nonfreeway bound traffic.[10] This technique has proven quite successful in San Diego, and no doubt has application in other locations.

The distance downstream of the meter must be adequate to permit vehicles to accelerate to freeway speeds from a stopped condition. The acceleration characteristics of heavy trucks and small economy cars, and the grade of the ramp are factors that must be considered.

<u>Diversion</u>

A major issue that is raised in connection with metering is the potential diversion of freeway trips to adjacent surface streets. Extensive evaluations of existing metering systems show that, while there are adjustments in traffic patterns after metering is implemented, these adjustments take many forms. Importantly, it is possible to predict the likely impacts of metering before it is installed. Factors that enter into the analysis include trip length, queue length, entry delay, and the availability, attractiveness and efficiency of alternate routes. The probable new traffic patterns, including diversion, can then either be accommodated in the design and operation of the system, or become part of a decision that metering is not feasible.

Metering may in fact divert some short trips from the freeway. In concept, freeways are not intended to serve very short trips, and diverting some trips may even be desirable if there are alternate routes that are underutilized. Diverting traffic from high volume, substandard, or other problem ramps to more desirable entry points should be an objective of metering where it is feasible. Such an action does require a thorough analysis of the alternate routes and the impacts of diversion on those routes, and improvements on the alternate routes when and where they are needed.

In Portland, city officials were very concerned about creating problems on parallel streets. Before the meters on I-5 were installed, the city and state agreed that if volumes on adjacent streets increased by more than 25% during the first year of operation, the state would either abandon the project or adjust the meters to reduce the diversion below the 25% level. Following meter installation, the increase in local street volume was not substantial. Evaluations of the impact of metering on adjacent streets have been conducted in Los Angeles, Denver, Seattle, Detroit and other cities. Significant diversion from the freeway to surface streets did not occur in any of these locations. Formal and informal agreements are common between state and local jurisdictions in connection with metering projects and close advance coordination between jurisdictions is highly recommended.

In some cases, there may not be feasible alternates routes due to barriers such as rivers, railroads or other major highways. Metering still can and does operate effectively where diversion is not an objective of the system. The systems in Denver, Northern, Virginia and Chicago, for example, operate under a so called nondiversionary strategy. In these systems metering rates are adjusted not only on the basis of demand and capacity, but ramp queue lengths as well. As the ramp queue gets longer, metering rates may be increased. If the queue gets long enough to impact local traffic (typically indicated by a detector at the top of the ramp), metering is terminated at least until the queue dissipates. Significant benefits in freeway flow and accident reduction still result from nondiversionary metering. The onset of mainline congestion consistently begins later in the peak period and ends earlier. Many days the mainline does not break down at all. Accidents and accident rates are also reduced. For example, in Denver it was observed that many drivers entered the freeway earlier in the morning. Peaks or spikes in volumes were thus leveled out over a longer period of time resulting in better utilization of freeway capacity.[4]

In each of the case studies, as well as on other systems, there was an increase in peak hour or peak period freeway volumes after metering was installed. In a number of cases the metered sections' volumes exceed 2,000 vehicles per lane. These are not random occurrences and can be attributed to the higher flow rates than those that occur under LOS F, or "break down" conditions. In some instances the improved mainline flow resulted in higher volumes on the metered ramps as well. In San Jose, an increase in some peak period ramp volumes has been observed after metering began. Before metering, when the mainline flow broke down, the ramps would back up also which reduced ramp volumes. After metering, the freeway no longer broke down and some ramp volumes over the peak period actually increased. Also, even with the ramp delays, some drivers that were using other routes found (or perceived) the freeway offered a faster trip and were attracted to the freeway. A well designed and operated ramp metering system improves operations and does not cause excessive diversion to adjacent streets. The latter is caused by excess demand and/or inadequate capacity.

Public Acceptance

A very important aspect of ramp metering is the need to gain public and political support. To the public, ramp meters are often seen as a restraint on a roadway normally associated with a high degree of freedom. Although definite benefits may be achieved by metering and have been demonstrated statistically, the benefits may not be recognized by individual motorists. A three minute wait at an entrance ramp, however, is easily recognized. A proactive public relations program should be an integral part of every metering project.

Unfortunately, the fear of a negative public reaction is used as an excuse and is, in reality, the true reason operating agencies reject ramp metering projects. Often cited are examples of "failures" due to public opposition. An implementing agency should expect and be willing to accept some criticism for applying an unpopular control device. Criticism is nothing new to most highway agencies, but ramp metering is. As a result, the agencies are not comfortable fully supporting a strategy that they have no experience with. Most of the failures of metering projects attributed to public rejection can be directly linked to a "business as usual" approach by the implementing agency.

Successful public relations campaigns explain the difficulties of mitigating freeway congestion problems and the cost effectiveness of management techniques such as ramp metering that improve freeway conditions for the taxpayers. In Minneapolis and Los Angeles, the "public" is has actually requesting additional metered ramps and this public input has become one of the factors in evaluating and selecting new metered locations. A promotional videotape from FHWA titled "Ramp Metering: Signal for Success" is an example of how the merits of ramp metering can be presented to the public. This 17 minute videotape, which is intended for citizens and public officials, explains the principles and benefits of ramp metering. It addresses key issues such as safety, efficiency, equity, and public relations. Loan copies are available from FHWA, and it can be purchased from the Institute of Transportation Engineers (ITE).

Equity

The complaint that ramp metering favors longer trips at the expense of shorter trips, on radial freeways particularily, can also be a controversial issue. Close-in residents, the argument goes, are deprived of immediate access to the freeway, while suburban commuters can enter beyond the metered zone and receive all the benefits without the ramp delays.

Again there are strategies that have been employed to mitigate the equity issue. In Detroit, the initial metering was operated only in the outbound direction to minimize the city-suburb equity problem. Once the effectiveness of the metering was established, the system was expanded with less objection. In Milwaukee where the question of equity has been a limiting factor in the expansion of metering, it is now proposed to expand the system by metering each ramp that contributes traffic to congested freeway segments. Metering rates will be designed to be comparable for all ramps. For example, if it is determined a 10% reduction in demand is needed on the freeway segment, metering rates will be established to reduce all ramp volumes by 10%. In addition, each ramp metering rate will be adjusted to the extent possible in order to assure average motorist delays are about the same for the outlying ramps as they are for closer in ramps.[13]

Even if only a few drivers experience increased travel times, there may still be objections simply because some have to wait at the ramps and other drivers do not. A reasonable analogy can be made between a metered freeway and a signalized arterial. Vehicles entering an arterial from a minor street must generally wait at a traffic signal while traffic already on the arterial is given priority. In both cases, the freeway and the arterial, the entering vehicles experience some delay in order to serve the higher volume facility.

Enforcement

The effectiveness of ramp metering, like any other traffic regulation, is largely dependent on voluntary driver compliance. As part of the public information effort, it should be made clear that ramp meters are traffic control devices that must be obeyed. The laws and penalties should be clearly explained. In cities where the advance publicity was positive and plentiful, violation rates are lower. Again, like any other regulation enforcement is needed. Cooperation with police agencies is essential. Effective enforcement requires good enforcement access, a safe area to cite violators, adequate staff, support by the courts, and good signs and signals that are enforceable. Enforcement needs must be considered and accommodated in the early project development and design stages, and enforcement personnel should be included in the planning and design of ramp metering projects.

HOV Bypass Lanes

No single traffic management strategy alone will solve urban congestion, and in fact, the basis of traffic management is the application of combinations of strategies that complement each other. Another strategy that is frequently used in combination with ramp metering is a HOV bypass lane. This is a parallel ramp or ramp lane that is reserved for HOV's to bypass the meter and thus provide a travel time incentive for carpools, vanpools, and buses. If the number of HOV's is too large, the occupancy rule can be modified or the HOV lane can also be metered. This latter strategy is used in San Diego where the HOV bypass lanes are metered but, because HOV volumes are lower, there is still a time advantage on the bypass lanes.

GUIDELINES FOR RAMP METERING

There have been a number of attempts to develop "warrants" for ramp metering, but it is difficult to establish a single set of conditions because of the many factors involved. There are few, if any, freeways that experience congestion that can not be improved by metering. The operation of the freeway, however, is only one of several factors that must be considered in evaluating the appropriateness of metering. Ideally, metering should be but one element of an overall freeway management program. However, ramp metering has proven successful in several cities without such programs.

The Manual on Uniform Traffic Control Devices (MUTCD) provides some general guidelines for freeway entrance ramp controls in Section 4E-23.[14] The Manual states that the installation of ramp meters should be preceded by an engineering analysis. It also describes the factors that should be examined in the study, most of which have been covered in this paper in greater detail. The Manual then gives a very broad description of when the installation of ramp meters may be justified. It simply states that entrance ramp signals may be justified when the total expected delay to traffic in the freeway corridor, including freeway ramps and local streets, is expected to be reduced. Minimum volume warrants were considered, but not used because freeway capacity does vary according to geometric, traffic and driver characteristics. Freeway operating conditions provide the most guidance. Candidate freeways for ramp metering are usually plagued with poor peak period conditions such as speeds of 30 MPH or less, and volumes of only 1200 to 1500 vehicles per lane per hour. Other candidates for metering include new and reconstructed facilities that may become overloaded shortly after they are completed. There is agreement among operating agencies that it is best to implement metering before conditions get severe. More restrictive metering rates can then be applied gradually as demand increases over time to help spread the peaks and thus maintain operational efficiency.

In Minneapolis/St. Paul, high accident locations and freeway operating conditions were the two most frequent factors used to identify the 150 additional metered ramps that are now being added to the system. Metering some ramps may also be required to complete a system, to prevent undesirable shifts in travel patterns, to address the equity issue, and/or to improve the quality of a merge operation.

CONCLUSION

Many urban freeways currently operate with peak traffic volumes well below capacity, the result of inefficient freeway operation. Ramp metering has proven to be one of the most cost-effective techniques for improving and maintaining the efficient operation of urban freeways during peak traffic periods. Metering is not a cure all for urban freeway congestion, but if conditions are proper, the effectiveness of a well planned and operated ramp metering system is undeniable.

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Ramp Metering Status in North America

CHICAGO: 91 computer controlled meters on several area freeways. First installation 1963.

COLUMBUS: 7 ramp meters on SR 315, I-70 and I-71, 6 fixed time and 1 local traffic responsive. First installation 1980. Expansion plans, replace existing fixed time meters with traffic responsive and add 10 locations under system control.

DALLAS: 35 fixed time meters on US-75. First installation 1971. Expansion plans, a freeway control plan is being developed for US-75 reconstruction.

DENVER: 26 computer controlled ramp meters (12 on I-25, 12 on I-225, 1 on I-270 and 1 on US-6), 6 ramps have HOV bypass lanes. First installation 1981. Expansion plans, 2 meters on I-70 in 1990-91.

DETROIT: 51 computer controlled ramp meters on I-94, I-375, and US-10 as part of the SCANDI System. Several HOV bypasses. First SCANDI installations 1981. Expansion plans, SCANDI has capacity for up to 250 meters.

FT. WORTH: 12 local traffic responsive meters on I-30 (all but one are temporarily removed for freeway reconstruction-to be replaced by 1993). First installation 1977. Expansion plans, 12 meters on I-30 in 1990, 207 metered ramps are planned under an area-wide management program for operation by 2004.

HOUSTON: 20 local traffic responsive meters on US-59, 2 ramps have HOV bypass lanes. First area installation 1975. Expansion plans, previously removed meters on Gulf Freeway (I-45) will be reinstalled as part of a computer controlled surveillance and control system beginning September 1989. Also 20 meters along the North Freeway by 1990 and approximately 15 along I-10 in the early 1990's

LOS ANGELES: 917 ramp meters operate on most freeways in the metropolitan area. Most of them are local traffic responsive and many have HOV bypasses. 32 meters operate all day. First installation 1968. Expansion plans, 110 additional meters in 1989 In nearby San Bernardino, metering on 22 miles of SR 91 is expected by 1993.

MILWAUKEE: 21 local traffic responsive meters on I-43 and I-94, 4 ramps have bus bypasses. First installation 1976. Expansion plans, 44 additional meters, many with HOV bypasses, as part of a comprehensive freeway management plan.

MINNEAPOLIS: 66 computer controlled metered ramps on I-35E, I35W, I-94, and I-694. Many have HOV bypasses. First installation 1970. Expansion plans, 150 mostly fixed time locations will be added in 1989-90. These will be upgraded to traffic responsive over several years.

NEW YORK: 9 traffic responsive meters on I-678 in Queens. 58 computer controlled meters on I-495 and two parkways on Long Island as part of the INFORM System. Installed 1988-89.

PHOENIX: 18 fixed time meters along I-17. First installation 1980. Expansion plans, 76 additional ramps along the I-17/I-10 corridor, many with HOV bypass lanes.

PORTLAND: 29 fixed time meters along I-5 and I-84, 15 with HOV bypasses. Expansion plans, 6 additional meters, including 1 freeway to freeway meter, in FY 1989-90. First installation 1981.

SACRAMENTO: 14 local traffic responsive meters on US-50 with some HOV bypass lanes. First installation 1983.

SAN ANTONIO: 9 local traffic responsive meters on I-10 and I-35 were removed for reconstruction, only 2 meters outside construction limits remain, one meter is on a freeway-to-freeway ramp. First installation 1977. Expansion plans, possible reinstallation of the removed meters as part of a future surveillance and control system.

SAN DIEGO: 81 computer controlled meters on several area freeways. 5 operate on freeway-to-freeway ramps at four interchanges. Many ramps have HOV bypass lanes. Expansion plans, an estimated 170 additional locations over the next 5 years. First installation 1968.

SAN JOSE: 60 local traffic responsive ramp meters operate in the San Francisco Bay Area predominately near San Jose on I-280, US-101, and SR 17. Some ramps have HOV bypass lanes. 2 freeway-to-freeway ramps are metered; mainline metering at the San Francisco Bay Bridge toll plaza with HOV bypass. First installation 1974. Expansion plans, metering is being considered throughout the Bay Area as part of an areawide traffic management system.

SEATTLE: 23 computer controlled meters along I-5, 11 have HOV bypasses. One meter controls a freeway-to-freeway ramp. Initial installation 1981. 2 locations On SR-520. Expansion plans, additional metering locations being designed on new I-90.

TORONTO: 10 computer controlled meters along the QEW operate during the AM peak in the eastbound direction. First installation 1975. Expansion plans, ramp metering is being investigated for HWY 401. Metering is also planned for Ottawa, Ont.

VIRGINIA: 26 computer controlled ramp meters (19 on I-395 and 7 on I-66) in Northern Virginia (Washington DC suburbs). First installation 1985. Expansion plans, feasibility studies underway for additional metering locations. Metering is also being considered in the Norfolk area.

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