

**A GUIDE TO SUCCESSFUL RAMP  
METERING IMPLEMENTATION**

by

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August 1994

## SUMMARY

Congestion is a major concern in most major metropolitan areas in the United States. The traditional engineering approach to mitigate congestion, adding capacity, is no longer an option in most cities. Therefore, metropolitan transportation officials are turning to modern technology to create a more efficient freeway system. One approach used to achieve this objective is the use of ramp metering as a congestion mitigator on freeways.

The problem faced by many metropolitan areas is the fact that they have not yet implemented ramp metering as a traffic management tool. One possible reason for this reluctance is a lack of guidelines for implementation. Hence, the goal of this paper is to provide documentation, a checklist, to be used during ramp metering implementation.

The objectives of this paper were to: first, establish precedent for the use of ramp metering as a long-term freeway congestion management tool; second, outline the major benefits which may be achieved through the use of ramp metering; third, outline the possible drawbacks to using ramp metering; fourth, identify other concerns which may contribute to the success or failure of ramp metering; and finally, identify guidelines which may be used during ramp metering implementation.

The approach used for this paper was to review available literature pertaining to the success, failure, and implementation of ramp metering systems in the United States. In addition, a questionnaire was developed and sent to transportation officials in metropolitan areas with both successful and unsuccessful ramp metering systems.

Due to the nature of the paper, the results of this paper are provided in a form which will be useful to transportation officials during implementation.

Application of the results will be achieved by outlining a fictional scenario of ramp meter implementation. Hence, an official will be able to compare this scenario with the local scenario and compare order, timing, decision, and the overall thought process undergone during the planning/implementation.

This paper is provided as a guide to serve those officials considering ramp metering as a technique to mitigate congestion. It should be used as a checklist of items to be considered, and should serve as a starting place for the planning and analysis stages of implementation.

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## INTRODUCTION

Congestion is a major problem in many urban areas. In 1988, the cost of congestion in the United States metropolitan areas exceeded \$34 billion. In New York City, that cost was over \$350 per resident, or \$1000 for every registered vehicle (1). Figure 1 depicts the cost of congestion as an "additional tax" in eleven major metropolitan areas in the United States as of 1988. These estimates continue to increase every year.

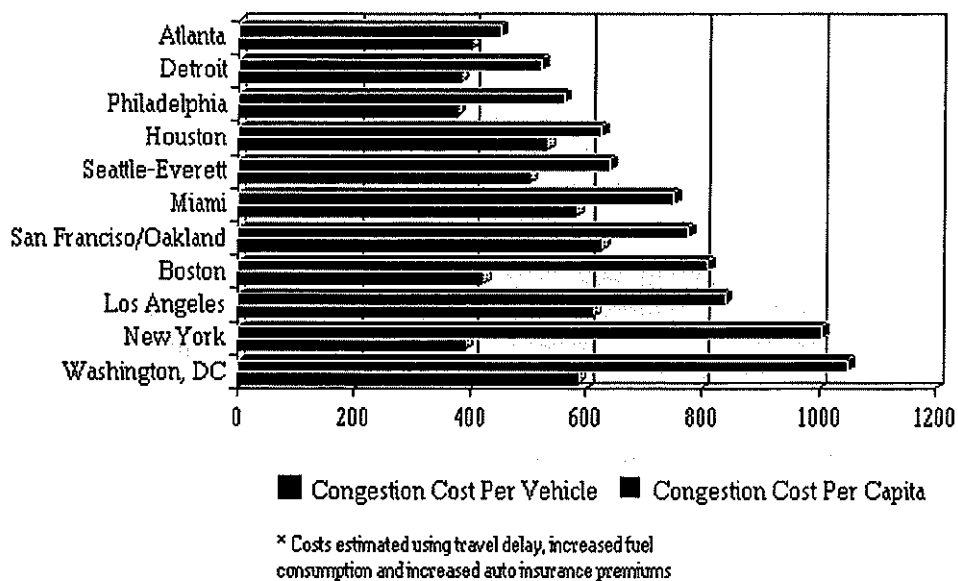


Figure 1. The Cost of Congestion Is Like a Tax on Our Mobility (1).

One of the most effective methods of reducing congestion is through the use of traffic management systems. Traffic management systems include techniques such as alternative work schedule programs, mainline control, ridesharing, congestion pricing, and entrance ramp control (1). Entrance ramp control in the form of ramp metering is the subject of this paper due to reluctance on the part of some areas to incorporate entrance ramp metering as a part of traffic management.

Ramp metering is an important congestion management element of any effective traffic management system. The benefits have been documented through extensive use in cities such as Los Angeles, California and Minneapolis/St. Paul, Minnesota. However, some of the most congested cities in the United States have shown reluctance toward ramp metering

implementation or have otherwise been unsuccessful in their attempts. Here, unsuccessful is defined as a city which has implemented ramp metering, has had problems with the system, and no longer has ramp metering in place. Cities such as Dallas, Texas fall into this group of metropolitan areas. One possible reason for not implementing ramp metering is a fear of the unknown: unknown effectiveness, unknown benefits, unknown drawbacks and unknown implementation procedure. Ramp metering implementation, like most system implementation, can be completed with relative ease if appropriate measures are taken.

### **Purpose of Paper**

The objectives of this paper are to:

1. Document successful metering systems, then present some of the benefits and possible drawbacks of ramp metering documented to date;
2. Identify some of the issues which should be considered before and during ramp metering system implementation;
3. Provide a guide to ramp metering system implementation.

### **Scope**

Although some of the same concerns and recommendations may apply to other types of metering such as freeway-to-freeway connector metering and main-line metering, the scope of the paper is limited to freeway entrance ramp metering. The paper is intended to provide a checklist of issues which should be considered during the implementation process, as well as some specific suggestions which have led to success in other areas. The content of this paper is based on a review of literature, case studies, and survey responses provided by representatives of several State Departments of Transportation.

## EXAMPLES OF RAMP METERING USE

As mentioned above, numerous State DOTs have been quite successful employing ramp metering as part of their traffic management system. While the measures of effectiveness may differ from area to area, the benefits are nevertheless significant. The following are brief examples of ramp metering use throughout the country. The ramp metering systems described demonstrate the different size and types of systems that can and are being used successfully. In addition, a common thread to these examples and to the ramp metering systems in 20 metropolitan areas in North America is the fact that all of the systems either have been, are being, or are planned to be expanded.

### Chicago, Illinois

Ramp metering experiments in the Chicago area were begun by the Illinois Department of Transportation in 1963 (6). The initial "ramp meters" were actually policemen stationed at entrance ramps. The policemen metered the ramps by stopping approaching vehicles, waiting a predetermined duration, and then letting them pass on a one-by-one basis. The initial experiments demonstrated effectiveness as a congestion control technique. The next step was automation. The current Chicago ramp metering configuration utilizes two standard, two-indication (red and green) traffic signals, positioned on either side of the ramp.

Chicago currently operates ramp meters on 109 ramps along its 136 centerline miles of surveillance (7). The majority of the ramp meters use local traffic responsive control, with only about twenty percent system control. As is the case with most metropolitan areas currently utilizing ramp metering as a traffic management strategy, it is considered very important to the overall congestion management system.

### Denver, Colorado

The Colorado Department of Transportation has implemented a system controlled ramp metering strategy in the Denver area (2). The system consists of six groups, each group being comprised of anywhere from one ramp to seven ramps. To accommodate queue storage, most entrance ramps are striped as two-lane metered ramps. Currently, a total of 28 ramps are metered in the Denver area. Additional locations are planned for construction on I-25, I-70, I-225 and I-270.

### Detroit, Michigan

The Michigan Department of Transportation incorporates ramp metering as a part of its Surveillance Control and Driver Information System in the Detroit area (5). The operation of ramp metering in Detroit began in 1982 on I-94. A preliminary analysis of the ramp metering system indicated that speeds on I-94 had increased by about eight percent. In addition, three-lane mainline volumes increased from 5600 vehicles per hour to 6400 vehicles per hour. Safety benefits were also shown to be significant with total number of accidents cut in half and the number of injury accidents decreased by 71 percent. Currently, The Michigan Department of Transportation meters a total of 49 entrance ramps in the Detroit area (17).

## **Long Island, New York**

The traffic management project on Long Island is the INFORM system which includes a 40-mile long by 5-mile wide corridor (5). The Long Island Expressway is the core of the network. Ramp metering began with 8 ramp meters in 1988 and is currently fully operational with greater than 50 ramp meters in place.

An initial analysis indicated that operation during the PM peak period had improved considerably (5). Mainline travel times decreased from 26 to 21 minutes, a 20 percent decrease, and an increase of speeds of 16 percent from 29 to 35 miles per hour. In addition, various other measures of effectiveness including emission measurements improved. One interesting observation made of the INFORM ramp metering effort is that it appears that metering four lane expressways such as the Long Island Expressway results in greater improvements than does metering wider freeways. This observation is intuitive in that unrestricted on-ramps can affect a two-lane (one direction) operation more than a three-, four-, or five-lane operation. Hence, ramp metering can have greater flow impacts on a two-lane operation.

## **Los Angeles, California**

The Los Angeles area use of ramp metering is the most extensive of any area in the United States (5). Initial installation of ramp meters in Los Angeles began in 1968. Results have been positive such that expansion has continued to present date and is planned for the future. Currently, Caltrans operates over 900 ramp meters in the Los Angeles metropolitan area (21).

## **Minneapolis / St. Paul, Minnesota**

The development of the current Twin City metering system has evolved over a period of 20 years (3). The first two ramp meters, both fixed-time controlled, were installed by the Minnesota Department of Transportation in 1970 along I-35E north of downtown St. Paul. This initial installation was upgraded to local traffic responsive control a year later. After 14 years of service, average peak hour speeds along this section remained 16 percent higher than prior to metering while peak hour volumes have increased by 25 percent.

The second section of ramp metering implemented in the Twin City area was installed as part of a full-scale traffic management system (3). The system included closed circuit television surveillance, highway advisory radio, variable message signs, and extensive "freeway flyer" bus service in addition to the 39 ramp meters and eleven ramp meter HOV bypass lanes. This project was begun in 1974 and after ten years of operation results are still impressive. Average peak period freeway speeds had retained an increase of 35 percent, peak period throughput had increased 32 percent and accidents had been reduced significantly.

The Minneapolis / St. Paul area currently meters 355 entrance ramps and, as with most areas where ramp metering is in place, the Twin Cities have more projects in design and construction phases (4). The long-term plan is to extend the traffic management system over the entire twin city freeway network, continuing the freeway-by-freeway implementation process as traffic conditions warrant.



## **San Diego, California**

The California Department of Transportation (Caltrans) began ramp metering operations in San Diego in 1968 (5). Currently, Caltrans operates a total of 130 ramp meters in the San Diego area on over 40 miles of freeway (20). Freeways on which ramps are metered frequently carry volumes greater than 2400 vehicles per hour per lane, with sustained operating volumes ranging between 2200 to 2400 vehicles per hour per lane.

## **Seattle, Washington**

The Washington State Department of Transportation began metering in the Seattle area in 1981 as part of the FLOW system (5). Initially, seventeen southbound ramps were metered during the AM peak period and five southbound ramps were metered during the PM peak. Currently, a total of 41 ramps are metered in the Seattle area.

A preliminary study of FLOW indicated mainline peak period volumes increased by 82 percent northbound and 62 percent southbound. In addition, travel times decreased by 10.5 minutes from 22 to 11.5 minutes. Finally, the accident rate decreased by 39 percent.

## **Summary**

While measures of effectiveness for analysis purposes differ from system to system, several common observations surface. In most cases described above mainline peak period volumes increased, peak period speeds increased and travel times decreased. The possible benefits of ramp metering are discussed further in a later section. However, as mentioned previously, one of the most telling fact about all of the systems described is that the systems have been expanded in the past and are planned for future expansion.

Table 1, on the following page, provides a summary of ramp metering in the areas covered above.

Table 1. Summary of Ramp Metering Examples.

City	No. of Ramps	Comments
Chicago, Illinois	109	policemen at first; mostly local traffic responsive now
Denver, Colorado	28	system controlled, broken into six groups
Detroit, Michigan	49	part of Surveillance Control and Driver Information System
Long Island, New York	50	part of INFORM system
Los Angeles, California	> 900	most extensive ramp metering use in United States
Minneapolis, Minnesota	355	utilize freeway-by-freeway implementation
San Diego, California	130	
Seattle, Washington	41	part of FLOW system

## TYPES OF RAMP METERING

In terms of systems, the previous section describes the extent and effectiveness of ramp metering systems in the United States. The section does not describe the specific control techniques of ramp metering systems. The design of the ramp metering system depends on several factors: ramp metering system funding, the degree of improvement desired, and existing traffic conditions (5). The design of the ramp metering system is defined by the type of control used. Hence, a brief description about the different types of control techniques used for individual ramps is needed.

There are basically three types of control used for ramp metering (8):

1. Fixed-Time Control
2. Local Traffic Responsive Control
3. System Control

Each of these control techniques offers different levels of control, traffic responsiveness, and required cost.

### Fixed-Time Control

Fixed-time control is the most basic of the three control techniques (3). Essentially, a fixed-time control ramp meter operates as a pre-timed traffic signal. The meter has a preset metering rate which is altered during different periods of the day. Traditionally, there are three metering rates: one for AM peak, one for PM peak, and one for off-peak periods. In addition to the vehicle metering device, detectors can be placed along the entrance ramp to give the controller presence, passage, and queuing information. Presence and passage detectors are generally used to activate the controller. When an automobile is not present, the meter may rest in "red" to avoid confusing approaching drivers.

The primary objective of fixed-time control is to break up platoons of vehicles entering a freeway by metering one-at-a-time at a maximum of about 900 vehicles per hour per lane. Fixed-time ramp meters are effective for smoothing flow onto the freeway to mitigate merge turbulence, for reducing the number of rear-end accidents at on-ramps, but are not as effective for controlling freeway volume levels (due to lack of local volume information) (5). Due to ease of installation, fixed-time control is an ideal strategy to use until ramps can be upgraded to a traffic responsive system.

### Local Traffic Responsive Control

The next level of control is local traffic responsive control (3). Local traffic responsive control utilizes a series of detectors in the mainline traffic lanes to determine local traffic conditions. These conditions along with the ramp demand are used to determine current metering rates.

One application of local traffic responsive control which has not been very successful is gap-acceptance metering (8). Under this type of control, detectors and a microprocessor are used to predict an acceptable merge gap for the entering vehicle. Due to the assumptions made regarding acceptable gap length, acceleration rate, sophistication and detectorization requirements, gap-acceptance is not a viable option in current ramp metering systems.

## **System Control**

System control is a type of traffic responsive control which is not limited to isolated ramps. In a system control scheme, many ramps along a freeway section or corridor are metered on a coordinated basis to achieve certain objectives. Local traffic conditions in the vicinity of all ramps in the system are used to set metering rates throughout the system. System control utilizes the components of local traffic responsive control and adds extensive communication hardware. In some cases, a centralized computer controlled system is implemented to be operated from a traffic operations center (2).

Another aspect of system control particularly attractive to major metropolitan areas is the ability to coordinate freeway on-ramps with the surrounding arterial network (5). This aspect of system control is known as integrated traffic control. The result of integrated traffic control is a system that operates on corridor-wide traffic information and controls. Integrated traffic control provides the following potential benefits: reduced costs, corridor wide surveillance, better motorist information, and quicker and coordinated use of all traffic control devices. The result is a system that operates to move motorists through a corridor based on information throughout the entire system, not just local conditions.

## **BENEFITS OF RAMP METERING**

Before any metropolitan area would consider implementation of a ramp metering system, a demonstrated history of benefits should first be examined. The following section presents some of the most significant benefits consistently achieved through the use of ramp metering.

### **Improved Mainline Flow**

The primary way that ramp metering improves mainline flow is by improving the efficiency of the freeway section. In this case, ramp volumes may actually increase, resulting in higher freeway volumes. In fact, previous sections have described cases where mainline volumes have increased over time, while vehicle speeds, travel times, and accident experience along the metered sections have remained significantly improved (3). The point here is that the freeway section generally can handle higher volumes without breaking down, which may provide evidence of increased capacity due to reduced turbulence and smoother merging operations. Improved efficiency is discussed throughout the following sections.

As many of the case studies have indicated, ramp metering results in many benefits to the freeway user (3). Freeway speeds, particularly indicative of freeway operations during peak periods, are consistently increased. In fact ramp metering in Minneapolis and Seattle has resulted in sustained peak hour speed increases between 16 and 35 percent (3). A residual of increased freeway speed is reduced freeway travel time. As was discussed earlier, one of the basic ideas behind ramp metering is to smooth the flow of traffic entering the freeway. Performance of this task helps to smooth peak demands which could result in breakdown of mainline flow. Evidence indicates that ramp metering actually increases capacity of freeway sections. Data from Minneapolis, San Diego, Seattle, Detroit and Denver show peak volumes in excess of 2000 vehicles per hour per lane, with sustained mainline volume increases from five percent to six percent over pre-metered operations.

One particularly attractive feature of ramp metering is the ability to change rates to adapt to the demands of the mainline flow. For example, ramp metering can be quite useful during incident conditions, especially where local bypass (alternate) routes are available (6). In these cases, ramp metering rates become more restrictive to encourage use of other routes. It should be recognized, however, that the amount of relief provided by ramp metering cannot overcome major losses in system capacity. For example, if an incident removes operation of a mainline lane, metering ramps more restrictively cannot overcome the loss since freeway capacity in this example is at least reduced by the capacity of the lane and ramp meters do not have that much available control.

### **Improved Safety at On-Ramps**

As discussed earlier, the primary function of ramp meters is to smooth the entry of vehicles onto freeways. This is performed by allowing one to three vehicles to pass through the ramp per green indication. The next metering phase is not begun until the vehicle has "passed" through the ramp and merged onto the freeway. This process of platoon breakup tends to reduce

turbulence, improve efficiency and lead to accident reduction (21). In the Seattle area, ramp metering along a short section of freeway resulted in a 39 percent accident rate reduction (5).

Safety benefits of ramp metering extend well beyond the cost of an individual accident (5). Take for example a typical metropolitan freeway during peak hour flow conditions. The two hour peak demand for the three lanes of flow is approximately 6000 vehicle per hour. Loss of one lane of the three due to an accident may reduce the freeway capacity by 50 percent. If it takes twenty minutes to remove the accident from the lane, a total of 2100 vehicle-hours of delay would be caused along with a two mile long queue and a recovery time of 2.5 hours. Obviously, the accident reduction benefit of ramp metering is a major benefit which is not always fully considered.

### **Reduced Bottleneck Flow Turbulence**

Generally, one of the more significant benefits of ramp metering is smoothing of freeway input to postpone or eliminate the onset of congestion (6). Under critical conditions at bottleneck locations, ramp meters should be operated in the most restrictive operating level to keep the freeway from breaking down. This is achieved not only by limiting the number of vehicles entering the freeway, but by smoothing the merge operation and mitigating turbulence at the on-ramp merge section. If turbulence enters the system and continues for a period of several minutes, the result can be sustained congestion lodged at an upstream bottleneck. Hence, the congestion does not occur at the on-ramp but at the nearest upstream bottleneck, say for instance a steep grade.

If congestion is established on a freeway, there is generally not enough control available to upstream ramp meters to affect the congestion at the downstream bottleneck (6). In this case, congestion is generally in place until overall freeway demand is reduced at the end of the peak period. It should be noted that no traffic management technique can perform the task of resolving congestion once established. It is the ability of ramp metering to control turbulence and postpone or eliminate the onset of congestion that makes it such an attractive management technique.

In one study of ramps in the San Diego area, it was concluded that merge conflicts were almost never the direct cause of flow breakdown where ramp metering was in place (11). However, merge conflicts were more likely to result in congestion at non-metered ramps, especially where platoon merging occurs. If this merge conflict situation occurs, ramp metering may be used to increase bottleneck capacity by reducing merge conflict as a cause of breakdown.

### **Diversion**

A concern of transportation officials in metropolitan areas considering ramp metering as a traffic management strategy is the impact of vehicle diversion on the surrounding arterial system (5). Evaluations of existing metering systems have indicated that while diversion does occur, it takes place in many forms. An analysis of the surrounding surface street system, current traffic patterns including origin destination information, and entry delay information can be utilized to predict new traffic patterns. The predicted diversion can then either be

accommodated in the design or used as a factor in the decision that ramp metering is not appropriate at that location.

Diversion can be a good thing if accounted for, designed for, and monitored. In some instances, diversion is simply the removal of short trips from the freeway (3). In principal, a freeway is not intended as a means of making very short trips. Diversion to nearby underutilized surface streets may be beneficial. Redistribution of the traffic to better utilize the entire network results in reduced system-wide delay and an improvement in traffic operations on the whole.

In the Chicago area, diversion has never been of a magnitude within a network at a given time that traffic patterns and levels of service on the surface streets were significantly affected (6). Generally, diversion effects are seen at the ramp queues, frontage roads and cross streets, but are negligible on a network scale.

As was mentioned earlier, diversion can take place in different forms. In the Denver area, the major diversion that was observed was time diversion (2). Here, ramp metering served to stretch out the peak period and smooth the demand curve. Specifically, at one on-ramp a 5 percent shift of AM peak period traffic to pre- or post-peak period traffic took place. This desirable shift in demand made better use of the network facilities.

### **Improved Merging Operation**

There are two cases of merging operation in which ramp metering can improve the operation of both the ramp and freeway. The first is a case of poor ramp geometrics such as a tapered entry ramp with no merge lane provided (6). This design often results in an entering vehicle or queue of vehicles waiting for an acceptable gap at the merge point. Such an operation is not beneficial to the ramp user, and may result in the merging vehicle accepting an insufficient merge gap, causing turbulence in the mainline flow. Ramp metering breaks up platoons, reduces queuing, and relieves the condition of stopped vehicles at the merge point and is thus, highly beneficial to the ramp user.

The second case applies to ramps with good geometric design (6). Here, any problems with merge operations usually result from the freeway traffic inappropriately yielding to entering vehicles. Freeway flow turbulence often results, which may ultimately lead to freeway flow breakdown. Ramp metering improves operations by smoothing freeway merging, releasing vehicles one-at-a-time and improving expressway flow.

### **Summary**

The previous section presented some of the benefits realized through the use of ramp metering. These benefits include reduction in accident experience, freeway operations improvements, benefits through trip diversion and improvement in merging operations. The next section presents some of the possible drawbacks of ramp metering.

## DRAWBACKS TO RAMP METERING

While ramp metering has proven to be an effective strategy in reducing congestion, it does have possible drawbacks. The following paragraphs present some of the pitfalls which can result from ramp metering system operation.

### Driver Inequity

A serious concern of transportation officials contemplating use of ramp metering as part of a traffic management system is the driver equity issue. The complaint is that ramp metering favors longer trips over shorter trips, especially on radial freeways (5). The argument continues that suburban area residents, entering outside the metered zone, are allowed access to the freeway and enjoy the benefits of freeway travel without the long ramp queues and delays that inner-city motorists endure.

The driver equity issue can be handled in one of several ways (5). In Detroit, ramp metering was initially implemented in the outbound direction only, avoiding the equity issue. Once results of ramp metering were apparent, there was very little opposition to expansion to the inbound direction. In Milwaukee, the driver equity issue became a major barrier to the expansion of the system already in place. The solution proposed by the local transportation officials was to make operation of the system as equitable as possible. They would achieve this by metering all ramps in the system in an equally restrictive manner. For example, if it was decided that ramps near the city needed to reduce input by 10 percent, then ramps in the suburbs would be restricted to reduce throughput by 10 percent as well. Efforts would also be taken to equalize ramp delay for all freeway users. It is important here to realize that whatever degree of equity is achieved, some motorists will be unhappy because it appears that they have to wait to access the freeway, while others do not. During implementation, transportation officials should make an effort to promote the equity of the system and highlight the improved freeway operation derived through the use of ramp metering.

### Diversion

Diversion as a potential benefit has been covered in a previous section. Diversion can be a ramp metering drawback as well. There are basically two classifications of diversion which may take place (6). The first type occurs when long delays occur at the ramp on a regular basis. This type of diversion results in permanently diverted motorists who do not reappear under less restrictive conditions. The second type of diversion occurs on a more "optional" basis usually at ramps where frontage roads and alternate routes are available. These motorists divert when conditions are unfavorable and use the metered ramp when queues are short or nonexistent.

Regardless of the type of diversion taking place, one of two things may result. First, diverted traffic may select alternate routes on the surrounding arterial system. If the alternate routes cannot handle the added volume, delays throughout the corridor may be incurred as a result of the nearby ramp meters. Second, diverted traffic may divert through nearby neighborhoods. This traffic is likely to be travelling at high rates of speed, creating unwanted hazards and generally altering the service for which local roadways are designed.



Diversion of motorists from the freeway may carry with it another danger. Motorists who divert from the freeway onto alternate routes such as nearby surface streets may be taking risks that are unknown to them. In most cases, motorists unfamiliar with the surrounding area will simply wait through the ramp queue and enter the freeway. However, if an unknowing motorist diverts from the heavily populated freeway to a less populated surface street in a bad neighborhood, the consequences could be much more serious than a few minutes of delay.

### **Excessive Queues**

One potential effect of ramp metering is the creation of long queues of vehicles which could extend back past the ramp entrance and eventually interfere with traffic operation on the a local street system (12). Due to this possibility, many operating agencies have installed a "flushing" feature. This feature can either detect when excessive queues are forming, then rest in green until the queue length is reduced to an acceptable level or simply meter at the least restrictive rate and then continue normal metering operations when queues return to acceptable lengths. It should be noted that long ramp queues and the associated delays tend to promote shifts in driving patterns such as time and route selection that are necessary for the success of the traffic management system.

Another issue that should be addressed in this section is the situation where congestion has set in on the mainline freeway (6). The control objective of ramp metering in this situation would normally be to limit the propagation of congestion upstream. However, more restrictive metering can result in excessive queues at the on-ramps which may eventually interfere with surface street operations. In this case, the question must be asked as to whether the excess demand should be stored on the freeway, contributing to congestion propagation, or on the ramps, resulting in interference of the surrounding arterial system.

### **Environmental Concerns**

One ramp metering concern which has developed recently is the realization that ramp meters which create long queues may result in localized carbon monoxide emission increases, or "hot spots" (22). While large-scale metering systems would generally benefit air quality significantly as to offset any localized carbon monoxide increases, localized "hot spots" may occur where long queues develop. In addition, the possibility that stops at ramp meters, followed by rapid acceleration for merging may result in excess emissions must also be considered.

While some may view this as a growing problem, one Minnesota Department of Transportation official cites the overall reduction in mainline congestion, the major contributor to automobile produced carbon monoxide emissions, as easily offsetting any "hot spots" that occur (23). In fact, while the concern is raised from time to time, it is not foreseen as a major problem in the near future.

Finally, as presented earlier, ramp metering may result in increases in mainline volume (22). One question posed is whether ramp metering encourages a modal shift to passenger vehicles, increasing traffic and vehicle miles travelled. Studies have indicated that the volume increase is primarily traffic diverted from other roadways. Hence, overall, the faster, more

consistent travel on freeways which results from ramp metering improves air quality to an extent that offsets the localized "hot spots".

### **Summary**

The previous section discusses some of the possible pitfalls that agencies may encounter as a result of ramp metering use. These pitfalls include the driver equity issue, motorist diversion and excessive ramp queues.

## CONSIDERATIONS

The previous sections dealt with specific cases of ramp metering, benefits and drawbacks of ramp metering. The following section begins to deal with some of the issues to be considered during the implementation process. These considerations should be accounted for early on during a ramp metering feasibility analysis since they are all crucial to the success of ramp metering as a traffic management tool.

### Design

A decision about the type of ramp metering system should be made prior to the feasibility analysis. As discussed earlier, the ramp type is based on the type of control used for the meter. Depending on the degree of improvement desired, the funding available for the system and existing traffic conditions, one type or a combination of types may be chosen (5). In some cases, simple metering may be sufficient for current demands, but future growth may warrant upgrading to local traffic responsive control, and finally to system control. Success of progressive control implementation strategy has been demonstrated in numerous metropolitan areas. However, the design of a ramp meter, or ramp metering system does not end with the type of control to be used.

Queue storage capacity is a concern when considering implementation of ramp metering. To mitigate the impact of long queues, adequate storage should be provided. In the city of Minneapolis, the staff uses a rule of thumb of ten percent of the premetered peak hour volume as a ramp storage requirement (3). If the present storage capacity is not sufficient, measures should be considered to provide extra capacity. Some options used by existing systems include widening the ramp to two lanes, restriping wide one-lane ramps to two lanes, or using part of the surface street approach for storage. If these or other measures are not adequate to provide sufficient storage, then metering may not be deemed feasible at that location.

Although queue storage is basic to the operation of ramp meters, it is also important to remember that queue storage must not encroach on the required acceleration distance. The distance from the ramp meter to the freeway entrance must be sufficient to allow vehicles to accelerate to freeway speeds from a stopped position (5). Acceleration distance design must consider acceleration characteristics of different classes of automobiles as well as the grade of the entrance ramp.

### Public Education and Information

There may be no better means of ensuring the success of a project than by winning and sustaining the support of the public. That is certainly the case with ramp metering projects. The problem with winning public support for ramp metering is that the majority of the public does not understand the purpose of ramp metering, cannot recognize the benefits of ramp metering, and sees ramp metering as a restriction placed on a "free" way (5). For these reasons, it is crucial that a public relations and education campaign be launched to gain support from the public.

A successful public relations campaign should do several things (5). First, it should explain the difficulty that lies in the management of congestion. Second, it should explain the cost effectiveness and benefits of congestion management techniques such as ramp meters. The campaign should attempt to educate the public while "selling" ramp metering as a congestion management tool. Finally, the public relations campaign should be ongoing. When changes are made to the metering system, the campaign should keep the public abreast.

Public relations campaigns can be quite successful. In Minneapolis and Los Angeles, the public is actually requesting expansion of the ramp metering system (5). This type of input has become a factor in selection of future ramp metering sites.

### **Special Applications**

Essentially there are only a few special applications of ramp metering, freeway-to-freeway connector metering being the first. This strategy is simply an extension of ramp metering to meter higher volume, higher speed freeway ramps (3). In most cases, connector metering is used as a supplement to ramp metering to provide more control to freeway input. There are several special concerns to be considered prior to use of connector metering.

Ramp queues on freeway connectors can be excessively long, and backup of these queues onto the freeway mainline could result in disastrous high speed collisions. Therefore, special considerations need to be given to the meter control system to provide for "flushing" of the ramp when queues get too long, and to the geometrics of the ramp to provide sufficient storage. In most cases, freeway-to-freeway connector metering is implemented only where two lane ramps are in place or where restriping can provide two lanes for metering operations.

Another special application of ramp metering is the use of High Occupancy Vehicle (HOV) bypass lanes (3). HOV bypass lanes are simply extra lanes, usually identified by painted diamonds on the pavement, at metered entrance ramps that allow carpools, vanpools and buses to bypass the ramp meter and corresponding queue. This becomes an incentive to motorists to use the HOV lanes, reducing the number of vehicles on the freeway and adding to the overall efficiency of the traffic system.

### **Metering Rates**

Perhaps the greatest impact on congestion management through ramp metering can be achieved through the metering rate strategy. The metering rate strategy selected depends on the type of ramp metering employed. In Chicago, the most basic metering rate strategy is based strictly on vehicle actuation (6). The ramp meters based solely on the presence and passage of vehicles. When a previous vehicle has passed and another vehicle is present, a green indication is displayed until passage. The strategy ensures that one-at-a-time metering is affected. It has been observed that the maximum sustained metering rate under this scheme is approximately 13 vehicles per minute.

The next level of metering rate strategy employs a predetermined metering rate for a given time of day based on historical traffic flow data (13). Metering inefficiencies are common under this type of metering strategy because on-ramp vehicles may be unnecessarily delayed if

on a given day, congestion dissipates more quickly than "normal." The positive side of this metering rate strategy is that it is effective for producing one-at-a-time merging, is relatively low-tech and low-cost, and does mitigate the turbulence caused by on-ramp merging operations.

Progressing to the next level of metering rate strategy is the use of real-time data to locally control metering rates. In these scenarios, metering rates are usually updated anywhere from every 20 seconds to every 5 minutes. Again, in Chicago, under this metering rate control strategy rates are selected based on mainline traffic data and ramp demand data from a predetermined set of 5 metering rates (6). The system updates the metering rate every 20 seconds based on 1-minute averages of traffic data.

In some areas, the real-time data is used by a central computer to control metering rates for a system of ramp meters. In Denver, the central computer collects data every twenty seconds from the local detectors and ramp controllers within the system (2). If a ramp is either in the most restrictive of six possible rates (mainline congestion) or if it is in a "flush" mode (ramp congested), the ramp is defined as critical. At this point, a system coordination plan is implemented. The system coordination plan progresses upstream of the critical ramp, placing each upstream ramp in a more restrictive metering rate until the ramp comes out of the critical state. If more than one ramp becomes critical, multiple plans are used.

Whatever metering rate strategy employed, there are certain limits to the metering rates used. The maximum metering rate which can be used effectively is approximately 900 vehicles per hour based on a four second cycle (3). If two vehicles are allowed to pass during a metering cycle, the maximum metering rate increases to approximately 1100 vph, based then on a six to seven second cycle. If additional metering capacity is needed, two lanes can be metered, with a transition to one lane prior the freeway merge point. Two lane metering may create a variety of problems and should be thoroughly analyzed before adoption.

In addition to an upper limit, there are practical lower limits which should be observed. It has been observed that compliance decreases drastically when vehicles must wait at the meter for longer than fifteen seconds. This places a lower metering rate limit at about 240 vehicles per hour. Chicago uses this rate as the minimum, or most restrictive rate for its ramp metering system (6).

## **Media Relations**

While a proactive public education and information campaign should be used to educate the public about the merits of ramp metering, good media relations can further aid in gaining public support. The motoring public needs information regarding traffic operations in order to make decisions such as route selection and departure times. For example, if a new ramp meter is being implemented, the motorists that normally use that ramp may want to divert to an adjacent ramp until the ramp is operating efficiently.

The media is in the business of "selling" information, especially free information. Good relations with the media entails an agreement that the transportation will supply information regarding traffic operations, including ramp metering, and that the media will disseminate the information to the public. The available traffic information draws customers to the media

source, be it radio, newspaper or television, and the traffic agency gets the information to the motorists.

One down side to close media relations may be the criticism of the media. All journalists want a story, and failure of congestion management, paid for with tax dollars, is a story that draws interest from the public. On the other hand, when the strategies are effective at alleviating or eliminating congestion the media are there to report that as well. One example involved the Denver ramp metering system (14). When daylight savings moved clocks ahead one hour in the Spring of 1987, all ramp controller clocks were set ahead. However, the central computer clock was inadvertently overlooked. The following Monday morning, ramp metering began one hour later than usual. Traffic conditions were the worst Denver had seen in years. The media noticed the conditions and initially had some fun. This mishap provided a significant contrast to the normally smooth operations with ramp metering in place and ultimately the media was more supportive of the system.

### **Summary**

The previous section outlines some of the major issues that should be addressed when considering the implementation of ramp metering as a congestion management tool. All of these considerations are critical to the success of ramp metering and in many areas have been reasons for lack of implementation. The following sections deal with the actual implementation process, concluding with a ramp metering system implementation guide.

## **IMPLEMENTATION**

Although ramp metering has been proven as an effective tool to mitigate congestion, many metropolitan areas continue to avoid using ramp metering as part of traffic management. One possible reason for this reluctance is an absence of guidelines for implementing ramp metering systems. The previous sections have outlined some of the existing ramp metering systems (proof of successful systems), benefits of ramp metering (motivation for implementing ramp metering), drawbacks (barriers to ramp metering implementation), and concerns (considerations during feasibility analysis and implementation) which should be addressed during the implementation process. What has not been quantified in previous research is a guideline for the actual implementation which, if followed, may increase the likelihood of a successful system. The definition of a successful system in this paper is a system which has been implemented, reduces congestion, is adopted by the public and remains in place. Obviously the first three criteria must take place before remaining in place, but the system should be long-term for it to be considered successful.

The following sections discuss the methodology adopted for obtaining information pertaining to ramp metering system implementation. In addition, the results of the data collection effort are reported. Finally, recommendations are provided in the form of a ramp metering system implementation guide.

### **Data Collection**

In an effort to obtain information regarding the implementation of some of the successful ramp metering systems in the United States, a brief questionnaire was constructed and distributed to professionals with knowledge of the systems. Figure 2 shows the questionnaire sent to professionals in the following cities: Chicago, Los Angeles, Seattle, Denver, Minneapolis/St. Paul, Detroit, Dallas, and San Diego.

The responses returned were quite informative, adding first-hand experience to the material obtained through literature review. Table 2 is a brief summary of the responses to each of the questions. Some of the responses were repeated by more than one professional, and some questions were not answered by all of those contacted. The information provided through the answering of these questionnaires was crucial to the compilation of the implementation guide since most of the literature dealt with this subject only slightly, if at all. The implementation guide which follows is a culmination of information from literature and information obtained through survey responses. At the very least, it should serve as a check list of considerations for traffic operations officials during the implementation phase of ramp metering.

***Please describe within each factor group, specific measures taken which contributed to the success of ramp metering in your region.***

1. Techniques/agreements used to aid in intergovernmental relations
2. Public information and education campaigns
3. Design considerations
4. Ramp selection criteria (selection of specific ramps that should/should not be metered)
5. Timing of various components (i.e. public information campaign, planning, design, etc.)
6. Media relations
7. Different applications of ramp metering
8. Attitude of agency personnel, government officials, etc.

***The following questions pertain to the current state of ramp metering in your region.***

***Please answer them as accurately as possible. Thank you.***

9. How many entrance ramps are currently being metered in your region?
10. The ramp metering system in your region is made up approximately of \_\_\_% fixed-timed, \_\_\_% local control, and \_\_\_% system control.
11. In your opinion, ramp metering is (not important, important, very important) to traffic management in your region.
12. In your opinion, what was the key factor that led to success in your region?

Figure 2. Implementation Questionnaire.



Table 2. Summary of Questionnaire Responses (4, 7, 15-21).

No.	Summary of Responses
1	local agencies involved in design process at early stage; promise to local communities that ramp queues will not interfere with surface streets; face to face meetings and trips to other cities to observe ramp metering operation; confer with city engineers and city council to increase comfort level of city staff; overwhelming success of demonstration ramp metering project won city support; transit cooperation met by providing HOV bypass where possible; willingness to mitigate and pay for negative impacts to local streets
2	prior to turn-on of new ramp meters: the news media is supplied with information through press releases, meetings, personal visits, press conferences, paid newspaper ads; need to early and on time; need to stress delay of few for benefit of system; temporary signing prior to turn-on of new ramp meters; informational meetings with citizens, city officials; handouts at ramps prior to activation
3	system designed to minimize queues interfering with surface streets; provide freeway standard merge and taper areas at all meters to maintain ramp safety during non-metering periods; two lane alternate release on normally one lane ramps; ramp volumes must not exceed metering volume + maximum storage; considerations for acceleration distance; provide for alternate routes
4	number of lanes selected based on volume of 900 vphpl, one-at-a-time metering; ramps selected for metering based on whether or not there is: sufficient number of lanes to handle demand, sufficient storage, room to add an HOV bypass lane; based on engineering judgment and computer simulation; meter nearly all ramps onto a freeway zone; meter numerous ramps to realize benefits of system operation
5	public relations one day prior to activating a new segment; public relations only when considerable resistance encountered; publicity of less value if it occurs too far in advance; sequence is: (1) planning, (2) funding request, (3) design, (4) installation, (5) public information and education, (6) activation; contact local agencies early on in planning and design
6	time is given freely for interviews; media is courted for its ability to disseminate information; meet twice a year with traffic reporters and as needed for special/unexpected events; media should be briefed to include expected random short-term delays; brief press release prior to new activation; maintaining strong media relations is mandatory for success;
7	use mainly for mainline congestion mitigation; introducing time of day meters for accident reduction; metering during off-peak periods may be perceived as unnecessary by public; freeway-to-freeway connector metering in overall control plan;

No.	Summary of Responses
8	as long as have demonstrated improvement, have had support in general; concerns of local jurisdictions eliminated once success was demonstrated; there must be a united front of participating agencies (enforcement, etc.); advent of ITS and strong federal approval has eliminated this problem;
9	0, 41, 130, 28, 355, 49, 136, greater than 900
10	four systems use 100 percent system control; 1 system uses 15 percent fixed-time and 85 percent system control; 1 system uses 80 percent local traffic responsive and 20 percent system control; 1 virtually 100 percent local traffic responsive control
11	(2) important, (6) very important
12	demonstrated improvement to mainline flow; articulate technically skilled staff to explain benefits of ramp metering; examples of formerly congested freeways now running free-flow at high speeds and high volumes; keeping system maintained and operating properly; positive results recognizable by motorists; reduction in accident rate of over 40 percent; careful selection of initial installations to get early success; willingness to respond to local needs

## IMPLEMENTATION GUIDELINES

The following guidelines take into account information from the implementation questionnaires and from the literature review. They are not intended as a "how to" to ramp metering, yet are intended to provide a checklist of issues that should be considered during implementation. The guidelines are placed into three groups based on the author's judgment of the relative importance of each. Additionally, the guide should provide some idea of how to deal with some of the possible pitfalls of ramp metering.

### Group 1

1. Consult the Manual on Uniform Traffic Control Devices for warrants for the use of ramp metering.
2. Use a staged ramp metering implementation strategy, starting with fixed-time or actuated control and progressing to local traffic-responsive or system control. This strategy will allow for early success without incurring excessive costs. Study other metropolitan areas prior to selection of a ramp metering strategy. Extensive literature has been produced on different metering rate schemes and should be consulted.
3. During the feasibility analysis, special attention should be paid to the selection of ramps to be metered. Avoid sites that will not provide adequate storage until such time that geometric improvements such as restriping to two lanes can be made. The maximum metering rate should be assumed 900 vehicles per hour per lane metered. Metering more than one lane can incur special problems and a thorough analysis should be performed beforehand. Select initial installations to ensure early success.
4. Maintain ongoing cooperative relations with all agencies involved. The agencies which should be consulted include state operating agencies, local jurisdictions, enforcement agencies, transit authorities, and any other agency which has a stake in the operation of the metering system. Meet often at first to establish a cooperative working relationship, then meet less frequently to maintain communications, perhaps every month for the first year, then every four months and for special events after the first year.
5. Make certain that the system is ready for activation when it is activated. If the system fails at first, it may not have the chance for later success.
6. Monitor ramp queues to avoid interference with operations on the adjacent surface street system. Study pre-metered ramp and merging volumes to establish projected queue lengths. If arterial interference is possible at a given ramp, an override function should be incorporated into the controller to "flush" the ramp when queues reach undesirable lengths.
7. Maintain the meters on a regular basis. Inspect all mechanical components, update the metering rates, and collect freeway and arterial flow data to ensure proper metering operation.

## **Group 2**

1. A proactive public information and education campaign should be undertaken to explain ramp metering to the motorists, provide logistics of activation, and point out the benefits derived through the use of ramp metering. Special emphasis should be placed on the possibility of minor delays for the benefit of the system on the whole.
2. Use a combination of law enforcement and the media to establish the seriousness of ramp metering compliance. Levy heavy fines for non-compliance and use the media to publish the fines. Also, appeal to the "good citizen" in the information and education campaign by explaining the importance of compliance to the success of the system. Cooperation of the local and state highway patrols may be established by including them in planning and design discussions.
3. Diversion is likely to take place at ramps where long queues form and delays occur. The adjacent surface street should be suitable for diversionary trips. The possible use of additional guidance signing along alternate routes may be considered.

## **Group 3**

1. Use HOV bypass lanes as incentives to carpool, vanpool or use the transit system.
2. Establish good media relations by establishing an open door policy with members of the different media. Provide good information to the media regarding both the successes and failures of the system.
3. For routes where the equity issue is likely to arise, meter outbound only initially, then add inbound metering once success is established.

Understand that ramp metering is not a cure-all for congestion. It has been demonstrated as an effective tool to mitigate congestion, but does have certain constraints which limit its potential. However, in almost every application, ramp metering as a congestion management strategy either postpones the onset of congestion or eliminates it altogether.

## APPLICATION OF RESULTS

For demonstration purposes, the following hypothetical ramp metering system will be implemented:

- Located in a hypothetical metropolitan city, population 500,000;
- Freeway condition during AM peak is congested mainly due to a bottleneck caused by a lane drop from three to two lanes on the inbound freeway lanes;
- The surrounding arterial system is well-developed and under-utilized;
- No HOV lane is present; and
- Operations during off-peak and PM peak hours are free-flow.

The following implementation plan would be used to ensure success.

- Traffic volumes, accident experience, travel time and delay data have been collected on the freeway and surrounding arterials.
- It was determined that the expected reduction in delay to freeway users exceeded added delay to ramp users and added travel time for diverted traffic and arterial street users.
- It was determined that there was adequate queue storage, suitable alternate routes, and there is demand in excess of the bottleneck capacity.
- Selection of fixed-time control was made due to the nature of the congestion problem. The congestion is due to a capacity reduction and the resulting bottleneck, always takes place during the AM peak, and can be alleviated by metering three ramps in the vicinity both upstream and downstream of the bottleneck. Upstream, metering will improve the efficiency of the freeway by reducing turbulence, downstream smoothed merging operations will reduce turbulence and prevent flow breakdown at the upstream bottleneck.
- The metering rate will be set at 500 vehicles per hour to establish a balance between restrictiveness and compliance. Close watch of the motorist behavior and the flow improvement will be necessary to adjust the rate if necessary. One-at-a-time metering will be utilized to minimize turbulence and maximize merge operation smoothing.
- The local transportation jurisdictions will be included in the planning and design from very early stages. Every attempt will be made to cooperate with local transit authority and local government. Funding of the ramp meters will be through the State Department of Transportation. Additionally, any problems with the arterial network caused by metering will be corrected by the state.

- The two ramps downstream of the bottleneck will be metered and the one ramp upstream will be metered. This selection was made because the flow downstream of the bottleneck is more critical than that upstream.
- Ramp queue storage is not foreseen as a problem, however the ramp width is sufficient (25') to restripe as two-lane if necessary.
- Ramp detectors will be placed along the ramp for presence, passage, and queue detection. The maximum metering rate of 900 vehicles per hour will be utilized to flush the ramp prior to interference with the upstream intersection.
- Pamphlets / flyers will be distributed upstream of the entrance ramps prior to activation. Distribution will begin one week prior to activation and continue through the activation date. The aim of the flyers will be to inform, educate, and "sell" the ramp meters to the public prior to activation. Information specific to the local congestion problem will be included to explain the necessity of the ramp meters and the minor ramp delays that are possible. Temporary signs will be posted upstream of the entrance ramps to advise of upcoming activation for those motorists who do not receive flyers. A public information hotline will also be established to answer any questions about the ramp meters. The hotline number will be included on the temporary signs.
- Local news media will be informed of the ramp meter activation, and advised of the probable "before and after" freeway conditions as a possible photo/newsreel opportunity. Press releases will be prepared one day prior to activation as well.
- Coordination between law enforcement officials and media coverage will be attempted to facilitate maximum compliance. Heavy fines (\$75) will be levied to encourage both compliance by motorists and surveillance by law enforcement. Compliance should not be a large problem if the public information and education effort is successful.

The above implementation plan, if carried out successfully, and if the system is ready for activation when activated, should ensure the initial success of the system. However, regular maintenance of the system must be carried out if long term success of the ramp metering system is to be achieved.

## CONCLUSIONS

This paper has provided a brief overview of some of the successful ramp metering systems around the United States. Metropolitan areas reviewed include:

- Denver, Colorado
- Minneapolis/St. Paul, Minnesota
- Long Island, New York
- San Diego, California
- Detroit, Michigan
- Seattle, Washington
- Los Angeles, California
- Chicago, Illinois

These case studies should serve as proof that successful ramp metering implementation is possible and demonstrate the various types and sizes of ramp metering systems being used.

Benefits of ramp metering are outlined to provide justification for selecting ramp metering as a congestion management strategy. The list of benefits discussed include:

- Improved mainline flow
- Improved safety at on-ramps
- Reduced bottleneck flow turbulence
- Diversion
- Improved merging operation

Again, these benefits are not intended to "sell" ramp metering. As a balance to the benefits, drawbacks are outlined to warn of some of the problems which may be dealt with when using ramp metering. Included in these problems are:

- Driver inequity
- Diversion
- Excessive queues

Additional concerns which may make system successful, or bring about its failure are also addressed. These concerns include:

- Design
- Public Education and Information
- Special Applications
- Metering Rates
- Media Relations

Accounting for these issues is crucial to assure successful implementation.

Finally, the results of questionnaire responses are presented followed by guidelines for ramp metering system implementation and application of those guidelines. These guidelines are based on study, consideration, and engineering judgement of information obtained both through the questionnaire and literature review.

## **RECOMMENDATIONS**

The use of ramp metering has been proven effective as a congestion mitigation tool. This paper should be used to provide support to those transportation officials considering ramp metering as part of the congestion management system. The implementation guidelines should be used as a checklist of considerations during the implementation process.

## **ACKNOWLEDGMENTS**

The author wishes to thank Mr. Dave Roper who served as mentor for this paper. Without his guidance and support, this paper would not have been possible. The author would also like to thank Dr. Conrad Dudek for his guidance towards completion of this paper. Special thanks go to those transportation professionals who generously gave of their time to respond to my questionnaire:

Glen Carlson	-	Minnesota Department of Transportation
Louis Lipp	-	Colorado Department of Transportation
Les Rubstello	-	Washington State Department of Transportation
Gordon Paesani	-	National Engineering Technology Corporation
Stuart Harvey	-	California Department of Transportation
Jim Carvell	-	Texas Transportation Institute
Joe McDermott	-	Illinois Department of Transportation
Anthony Cioffi	-	Illinois Department of Transportation
Dave Roper	-	Roper and Associates



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