CONTENTS

Foreword

Executive Summary

1.0 Introduction
  1.1 Why Freeway Management?
  1.2 Types of Congestion
  1.3 Existing Freeway Management Strategies
  1.4 Purpose of this Monograph

2.0 Freeway Management Strategies for Recurring Congestion
  2.1 Freeway Flow Characteristics
  2.2 Freeway Management Control Strategies
  2.3 FMS Selected for Further Evaluation

3.0 Mainline Metering
  3.1 The Mainline Metering Concept
  3.2 Previous Mainline Metering Experience
  3.3 Mainline Metering Research Objective
  3.4 Mainline Metering the Non-Bottleneck Condition

4.0 Development of a Freeway Management System
  4.1 An Application of Systemwide Freeway Management
  4.2 Isolated Applications of Mainline Management

5.0 Implementation Issues of Mainline Metering, Congestion/Peak Period Pricing and SMART Corridors
  5.1 Survey Findings
  5.2 Hypothetical Implementation/Marketing Scenario
  5.3 Summary of Implementation Issues
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

Appendix A

Appendix B

Appendix C

Glossary

Bibliography
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Congestion Trends</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The Cost of Congestion Is Like a Tax on Our Mobility</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Speed Flow Relationships Under Ideal Conditions</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Density Flow Relationships Under Ideal Conditions</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Relationships Among Demand, Capacity &amp; Congestion</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>On-Ramp Metering Configuration</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Mainline Metering: Bay Bridge, San Francisco</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Connector Metering Examples: San Diego, California</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Traffic Flow or Capacity Loss Due to Congestion</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Development of a Freeway Management System</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Toll Plaza and Metering Point Design Concept</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Typical Examples of Reductions in Mainline Freeway Capacity</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Examples of Capacity Reduction at “T” or “Y” Freeway Interchange</td>
<td></td>
</tr>
<tr>
<td>B-1</td>
<td>Freeway Study Area Network</td>
<td></td>
</tr>
<tr>
<td>B-2</td>
<td>Mainline Service Volume = 1800 VPHPL</td>
<td></td>
</tr>
<tr>
<td>B-3</td>
<td>Mainline Service Volume = 1850 VPHPL</td>
<td></td>
</tr>
<tr>
<td>B-4</td>
<td>Mainline Service Volume = 1900 VPHPL</td>
<td></td>
</tr>
<tr>
<td>B-5</td>
<td>Mainline Service Volume = 1950 VPHPL</td>
<td></td>
</tr>
<tr>
<td>B-6</td>
<td>Average Speed for Mainline Service Volume = 1800</td>
<td></td>
</tr>
<tr>
<td>B-7</td>
<td>Average Speed for Mainline Service Volume = 1850</td>
<td></td>
</tr>
<tr>
<td>B-8</td>
<td>Average Speed for Mainline Service Volume = 1900</td>
<td></td>
</tr>
<tr>
<td>B-9</td>
<td>Average Speed for Mainline Service Volume = 1950</td>
<td></td>
</tr>
<tr>
<td>B-10</td>
<td>Network Travel Time for Mainline Service Volume = 1800 VPHPL</td>
<td></td>
</tr>
</tbody>
</table>
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

B-11  Network Travel Time for Mainline Service Volume = 1850 VPHPL
B-12  Network Travel Time for Mainline Service Volume = 1900 VPHPL
B-13  Network Travel Time for Mainline Service Volume = 1950 VPHPL
**LIST OF TABLES**

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traffic Management Strategies for Recurring and Non-Recurring Congestion</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Freeway Management Strategies and Techniques</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Comparison of Mean Flow Rates and Mean Speeds: Baltimore Harbor Tunnel</td>
<td></td>
</tr>
</tbody>
</table>
The movement of people, goods and services is the foundation of economic activity required for today’s highly competitive marketplace. An efficient transportation system is a prerequisite to this mobility, and highway infrastructure is a crucial element of this system. However, a majority of the nation’s freeways are experiencing increasing levels of congestion, resulting in extensive delays, reduced productivity, wasted energy and a frustrated driving public. The traditional solution of building more roads is no longer feasible in many urban settings due to financial and environmental constraints.

These concerns have created the need for improved congestion management on our nation’s freeways. Across the country several freeway management strategies (FMS) have already been employed to make better use of existing freeway capacity. This monograph further develops the concept of FMS as a means to improve freeway mainline operations, identifies different types of FMS that can be pursued and, most importantly, explores an innovative freeway management approach that can be used for the development of an areawide freeway management system.

Chapters 1 and 2 introduce the concept of freeway management and identify the types of strategies to be considered. This discussion draws upon several information sources including publications of the Transportation Research Board (TRB), Federal Highway Administration (FHWA), Institute of Transportation Engineers (ITE), other state and local agencies, and individual authors; proceedings from several traffic management conferences; surveys of transportation operators; and interviews with transportation professionals.

The remaining chapters research the freeway management potential of mainline metering for both areawide and isolated applications. A simplistic freeway network is used to simulate mainline metering and quantify likely performance characteristics. Based on these results and previous experience with mainline metering, an areawide freeway management system is proposed. This system will utilize mainline metering to manage the freeway as a closed system in an effort to obtain the highest efficiency for the facility.

Research results indicate that a proposed freeway management system utilizing mainline metering can maximize freeway efficiency. But this monograph cannot resolve all the issues associated with this type of approach. To this end, several planning, operational, and design considerations and implementation concerns are identified as areas needing further research, possibly via white papers. This investigation should eventually lead to a demonstration project in a region “willing to try” an innovative approach to managing areawide freeway congestion.
The concept of managing the freeway system via mainline metering is a natural evolution of the current trend in freeway operations. This is one of the last unexplored tools that can be used to improve the efficiency of our freeway system. It is no longer a question of if this approach should be pursued, but rather a question of when.

Acknowledgments

This monograph is one of a series of research endeavors conducted under the auspices of the William Barclay Parsons Fellowship, an annual research award provided by the Board of Directors of Parsons Brinckerhoff Quade & Douglas, Inc. “to perpetuate the ideals and achievements of its founder, William Barclay Parsons.” I wish to express my gratitude to the Parsons Brinckerhoff Board of Directors for providing the opportunity to conduct the William Barclay Parsons Fellowship for 1992 and the support needed to produce this monograph. I also want to express my gratitude to the Career Development Committee, especially Mr. Paul Gilbert, for its support and guidance throughout the Fellowship year.

The development of this monograph would not have been possible without the many conversations, continual feedback and constant support provided by my two technical mentors, Mr. Charles Fuhs and Mr. Kern Jacobson. Special thanks to Chuck and Kern for their contributions. I also want to express my gratitude to Dr. Donald Capelle for his constructive comments and support during the Fellowship year.

In addition, I would like to acknowledge the assistance of a review group of individuals who graciously donated their time to discuss ideas and provide feedback in the development of this monograph. These individuals include: Mr. Peter Briglia, Washington Department of Transportation; Mr. Dave Roper, Roper and Associates, Inc.; Mr. Jim Robinson, Federal Highway Administration; Mr. Glen Carlson, Minnesota Department of Transportation; Ms. Heidi Stamm, Pacific Rim Resources; Ms. Donna Carter, Frank Wilson & Associates, Inc.; Dr. Wilfred Recker, U.C. Irvine Institute of Transportation Studies; Dr. John Leonard, U.C. Irvine Institute of Transportation Studies; Mr. William McCasland, Texas Transportation Institute; Mr. Joseph McDermott, Illinois Department of Transportation; Mr. Robert Dale, New Jersey Turnpike Authority; and Ms. Lynda South Webster, Virginia Department of Transportation.

I would also like to acknowledge the word processing and graphics staff in the Orange and New York offices for their greatly appreciated efforts in the development and production of this document. Special thanks are also due Orange office managers Mr. Eric Keen and Mr. Dave Levinsohn for their patience, understanding and support.
The final and most important “thank you” belongs to my lovely wife, Christine Haboian. Whether enduring my jubilations or trepidations, she was always supportive of this endeavor and even assisted in its development. Her constant encouragement and understanding were a source of inspiration throughout the Fellowship year.

Kevin A. Haboian
Professional Associate
Parsons Brinckerhoff
May 1993
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

EXECUTIVE SUMMARY
EXECUTIVE SUMMARY

Background

Large population and employment growth, coupled with the reliance on the interstate system as the primary means of urban mobility, has placed a tremendous burden on our freeway infrastructure. Adding additional lanes is no longer the solution due to a highly developed urban framework, lack of available right-of-way, latent demand, and increased environmental regulations. Freeway management strategies (FMS) make better use of the existing infrastructure by maximizing traffic flow for both vehicles entering via on-ramps and those already on the freeway mainline, thereby increasing overall freeway speeds and reducing overall travel times. FMS, specifically freeway mainline control strategies, have struggled for acceptance in the United States in much the same way that ramp metering and HOV facilities did until they became widely accepted traffic management tools. One explanation for these lengthy acceptance processes is a lack of understanding as to the benefits to be achieved.

FMS For Further Evaluation

Freeway management strategies can include ramp metering, HOV lanes, overhead lane control signals, freeway mainline metering, variable speed control, SMART corridors, and congestion pricing. An ad hoc survey (reproduced in Appendix A) of transportation specialists was employed to determine which of these strategies offered the most potential in managing congestion. Survey participants included individuals from those geographic areas currently experiencing significant congestion. Respondents indicated that mainline metering, congestion pricing, and SMART corridors could improve freeway operations. While congestion pricing and SMART corridors are currently the subject of various research endeavors, attention to mainline metering — controlling the amount of traffic entering a mainline freeway segment to provide improved travel downstream of the control area — is virtually nonexistent.

Benefits of Mainline Metering

A computer simulation was conducted using the INTRAS model to determine if mainline metering can provide additional freeway operational benefits beyond those achieved from ramp metering. Simulation results are presented in detail in Appendix B and summarized below:
As the freeway mainline volume increases, ramp metering appears to increase the downstream vehicular throughput by approximately two to four percent. This result is basically consistent with experiences with ramp metering to date.

Ramp metering appears to increase the freeway speed and the average speed for the entire freeway network compared to the no-control scenario. In addition, the more restrictive the metering rate, the better level of operation on the freeway (in terms of higher speeds and lower travel times).

Combining mainline metering with ramp metering resulted in the same or, in several cases, slightly higher downstream vehicular throughput compared to the no-control and ramp metering alone scenarios.

As mainline service volumes increase, the freeway speed for the ramp metering alone scenario decreases. The addition of mainline metering provides much improved freeway conditions downstream of the mainline meter. This improvement is balanced by the added travel time incurred upstream of the mainline meter.

When mainline metering is combined with ramp metering, the average freeway speed for vehicles originating upstream of the mainline meter remains unchanged. However, the freeway speed downstream of the mainline meter increases.

Vehicles originating from on-ramps downstream of the mainline meter are provided better freeway conditions compared to the no-control and ramp metering alone scenarios. Consequently, vehicles originating from these downstream on-ramps experience lower freeway travel times.

These results indicated that mainline metering can improve freeway operations downstream of the mainline meter. Most importantly, they indicated that this can be accomplished without increasing the overall delay for vehicles originating upstream of the metering location. In addition, vehicles accessing the freeway from metered on-ramps downstream of the mainline meter are no longer entering a congested freeway mainline, thus slightly reducing overall travel times. These findings appear to indicate that mainline metering may serve as an appropriate freeway management tool.

**A Freeway Management System**

A potential application of systemwide freeway management using mainline meters would be based on managing freeway demand as a closed system to maintain the optimum number of vehicles on the freeway before a breakdown occurs. This approach has been
used by utility companies for some time. When electrical demand exceeds the amount of current that power lines can accommodate, service is either rerouted or delayed until there is room, or available capacity, to send the electrical current. Similarly, if the volume of traffic entering a freeway section can be maintained just below the freeway section’s capacity, the most efficient utilization of the roadway is achieved. The following performance characteristics can be expected with this systemwide mainline metering strategy:

- Mainline meters may be located at 8- to 15-mile intervals.
- Within these intervals, vehicles using the freeway will experience non-congested conditions.
- HOVs could gain travel time benefits via bypass lanes provided at the mainline meters.
- Depending on the number of additional lanes provided at the mainline meter, queue lengths may extend from a quarter mile up to two miles.
- Overall travel time for vehicles entering the freeway from non-metered ramps (ramps external to the controlled freeway section) would be the same as without the mainline meters.
- Overall travel time for vehicles entering from metered ramps would be slightly reduced since they will now be entering a mainline freeway experiencing non-congested conditions.

There are several planning, operation and design considerations that must be addressed before this type of freeway management system can be successfully implemented. These considerations are identified as areas of research deserving further investigation.

**Implementation Issues**

To gain an understanding of the likelihood of implementing mainline metering, congestion pricing or SMART corridors, a more detailed survey was conducted of individuals who would be responsible for pursuing these strategies in their respective areas. Overall, survey participants indicated that mainline metering and SMART corridors were more likely to be implemented than congestion pricing. For all cases, a champion (a state or local leader) was recommended to promote each strategy, and a steering committee composed of regional representatives was deemed necessary to address technical and institutional
issues. It was also recommended that traditional approaches for dealing with local area congestion should be exhausted before considering any new strategy, and that local area motorists must be so frustrated with the existing congestion situation that they are willing to try something new to improve traffic conditions. Public and political involvement was considered essential early in the project development process. The above survey results (reproduced in Appendix C) were used to formulate a hypothetical implementation/marketing scenario for mainline metering.

Conclusion

Depending on the goals of the particular freeway operating agency and existing congestion conditions, FMS can provide more effective highway utilization than is currently being achieved. With the interstate highway system nearing completion, and given the finite amount of available highway capacity, this research indicates that mainline metering can be a viable transportation management tool. However, before mainline metering implementation can be considered, a demonstration project should be conducted to validate research findings and address the identified planning, operation and design considerations.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

1.0 INTRODUCTION
1.0 INTRODUCTION

1.1 Why Freeway Management?

The need for freeway management strategies (FMS) essentially originated with the establishment of the Interstate Highway Program in 1956. The purpose of this program, which financed construction of the 42,800-mile National System of Interstate and Defense Highways, was to link different geographic areas with roadways that would provide motorists with a high level of service. Providing several travel lanes on a roadway facility, while minimizing the amount of intersecting roadways, enabled vehicles to reach their destination at speeds and travel times much improved over the traditional arterial system.

Although this system initially worked very well, large growth in urban population and employment, coupled with the reliance on the interstate system as the primary means of urban mobility, has placed a tremendous burden on our urban freeway infrastructure. Figure 1 indicates that the number of vehicles experiencing congestion on our urban highways has nearly doubled from 1975 to 1990. In many areas, traffic is virtually gridlocked, and these costly conditions can last for several hours in both the morning and evening peak periods. In 1988 the total cost of congestion in U.S. metropolitan areas exceeded $34 billion. As shown in Figure 2 this translates into a “congestion tax” that exceeds $500 per

![Figure 1: Congestion Trends](image)

Figure 2: The Cost of Congestion Is Like a Tax on Our Mobility

In 1988, the total cost of congestion in US metropolitan areas exceeded $34 billion. In Washington, DC this "congestion tax" was equivalent to $570 per resident and $1,050 per every registered vehicle.

Source: Texas Transportation Institute, Roadway Congestion in Major Urbanized Areas 1982 to 1988, p. 63.
vehicle in our metropolitan areas. This congestion increased travel times, decreased travel speeds, caused unpredictable operations, and increased accident potential, operating costs, and air pollution. These products of congestion ultimately aggravate and frustrate the driving public.

Experience has shown that building additional freeway lanes will not solve the problem. Additional lanes frequently attract traffic soon after their implementation as a result of latent demand, resulting in freeway speeds and travel times that are approximately the same, or sometimes worse, than conditions before implementation of the improvement. These conditions can occur whenever demand exceeds the added capacity of the improvement. In addition, it is becoming increasingly difficult to widen our existing highways due to the development of the surrounding urban framework, increasing right-of-way costs and environmental constraints.

To combat growing congestion on the urban freeway system, FMS are needed to make better use of the existing infrastructure. FMS involve operational improvements intended to maximize traffic flow for all vehicles using the freeway, those entering via on-ramps and those already on the freeway mainline. FMS are not intended to solve or meet the large demand for freeway travel in our urban areas, but rather to improve congestion management and thereby increase overall freeway speeds and reduce overall travel times. Thus, by managing traffic to optimize use of the existing infrastructure, FMS can benefit all vehicles using the freeway.

It is appropriate to consider traffic management strategies that can better manage freeway operations, including strategies that manage or control the freeway mainline. The intelligent vehicle highway system (IVHS) program will be developing technologies and products that provide a more enhanced and reliable means of transmitting and disseminating information. It is important that the profession be prepared to take full advantage of the opportunities that these new technologies will provide. FMS can play a major role in the future management of our urban highways.

1.2 Types of Congestion

Traffic congestion on urban freeways can be categorized into two basic types: recurring congestion and non-recurring congestion.

Recurring congestion is predictable because it generally “recurs” at the same locations on a daily basis. An obvious example is the peak period freeway congestion experienced by motorists accessing their place of employment. This type of congestion occurs as a result of vehicular demands for the freeway facility that exceed its available capacity. This excessive demand creates a recurring operational bottleneck.
Non-recurring congestion is unpredictable because it is the result of dynamic events (e.g., special events, freeway incidents) that reduce the freeway level of service. The type and severity of the dynamic event can vary significantly (e.g., accidents, spilled loads, disabled vehicles); and the event may create a temporary hazard or a bottleneck resulting in significant congestion.

Both recurring and non-recurring congestion can have a detrimental effect on freeway traffic operation. However, there are various FMS available to mitigate each type of congestion.

### 1.3 Existing Freeway Management Strategies

Table 1 summarizes the existing traffic management strategies that can be used to improve freeway traffic operation during recurring and non-recurring congestion. The selection of a particular management strategy is dependent upon the desired operational concept to be pursued. For recurring traffic congestion these operational concepts can be categorized as involving either capacity management, demand management or geometric improvements.

<table>
<thead>
<tr>
<th>Type of Congestion</th>
<th>Operational Concept</th>
<th>Management Strategy</th>
</tr>
</thead>
</table>
| RECURRING          | • Better use of available capacity by maximizing vehicular throughput  
                     • Reduce demand through various operating policies  
                     • Provide geometric improvements  | • Entrance Ramp Control  
                     • Mainline Control  
                     • Priority Control  
                     • Corridor Control  
                     • Work Rescheduling  
                     • Ridesharing  
                     • Transit Subsidies  
                     • Congestion Pricing  
                     • Parking Fees  
                     • New Construction  
                     • Restriping  |
| NON-RECURRING      | • Minimize impacts of capacity-reducing events  | • Events Management  
                     • Incident Management  
                     • Traffic Surveillance  
                     • Driver Information Systems  
                     • SMART Corridors  |

Table 1: Traffic Management Strategies for Recurring and Non-Recurring Congestion
Capacity management involves managing vehicular demand accessing the freeway to optimize the available capacity on the freeway mainline and achieve the desired level of service. Traffic management strategies exemplifying capacity management include entrance ramp control, interchange connector (freeway-to-freeway) control, mainline control, priority control and corridor control. Demand management involves reducing the number of vehicles using the freeway through various regulating policies. Such strategies can include work rescheduling, ridesharing programs, parking management, transit subsidies and congestion pricing. Geometric improvements involve providing additional travel capacity including, but not limited to, adding additional lanes, restriping to create the additional lane, or constructing new freeway facilities.

As mentioned previously, dynamic events on the freeway are the source of non-recurring congestion. Due to the unpredictability of these events, the proper management of non-recurring congestion is dependent on a well organized incident and special event management program. This program usually consists of various mechanisms that traffic operators, emergency personnel and the public can use to detect (or report) incidents, transmit and receive information concerning an incident, and respond to clear the incident in the most expeditious manner. Example capabilities include closed circuit television cameras (CCTV), motorist call boxes, detector-based surveillance systems, police and service patrols, highway advisory radio (HAR), changeable message signs, and other tools required to detect, evaluate and respond to freeway incidents.

Many of the strategies discussed in this monograph are used to better manage traffic congestion due to an incident. In addition, there has been extensive research and documentation of the management techniques addressing non-recurring congestion (Reiss and Dunn, 1990; Ritchie, 1991; Roper). It should also be noted that non-recurring congestion is the result of freeway incidents (usually accidents) that occur for essentially two reasons: human error or the prevailing traffic condition. The human element of non-recurring congestion is difficult to control; however, if the freeway condition can be managed to provide a more balanced freeway operation, this could translate into reduced incidents and a corresponding reduction in freeway delay.

1.4 Purpose of this Monograph

The purpose of this monograph is to further develop the concept of FMS to more effectively manage recurring traffic congestion. Specifically, it will focus on mainline metering and other capacity management techniques — FMS that make better use of our existing or available freeway capacity. These FMS are used to develop a proposed freeway management system as a means of better managing traffic congestion.
The traditional solution of providing additional capacity will not alone solve the problem. A highly developed urban framework, lack of available right-of-way, latent demand, and increased environmental regulations make it increasingly difficult to implement additional capacity. It is recognized that demand management strategies can minimize recurring congestion by reducing the number of vehicles on the roadway. Though beneficial, most demand management strategies do not have the capability to manage vehicles to maintain the desired operating condition on the freeway facility.

FMS, specifically freeway mainline control strategies, continue to struggle for acceptance in the United States, just as ramp metering and high occupancy vehicle (HOV) facilities struggled for almost 20 years before they became widely accepted and utilized traffic management tools. One reason for this lengthy acceptance process appears to be a lack of understanding regarding the benefits that can be achieved with traffic management. For this reason, attention is also directed at the implementation and marketing process. This process is extremely important whenever a new or innovative transportation solution is pursued.

This chapter highlighted the overall goal of this monograph: to focus on FMS that make better use of available freeway capacity to address recurring traffic congestion. Chapter 2 presents a brief explanation and summary of existing and potential FMS, noting the advantages and disadvantages of each. From this list of strategies, freeway mainline metering was selected for more detailed evaluation for its potential to manage traffic congestion. This evaluation, presented in Chapter 3, is based on opinions from some of the most reputable professionals in the field and quantifiable results obtained with the INtegrated TRAffic Simulation (INTRAS) model. The results of this evaluation, together with previous mainline metering experiences, were used to develop a proposed freeway management system. This proposal, discussed in Chapter 4, is based on managing freeway demand as a closed system to obtain the most efficient use of the freeway facility. Chapter 5 presents a brief discussion of the issues and concerns that appear appropriate when considering implementation of freeway mainline control strategies. These issues and concerns are based on a survey of the agencies and individuals who are responsible for implementing freeway mainline strategies in their area.

This monograph has been written to benefit a cross section of individuals interested in better managing freeway traffic congestion. Whether the reader is interested in general information regarding the types of FMS that can be considered (Chapter 2), more detailed information concerning freeway mainline metering (Chapter 3) and its potential application in an areawide freeway management system (Chapter 4), or information regarding implementation of transportation solutions (Chapter 5), it is hoped that this monograph will assist in attaining each particular objective.
2.0 FREEWAY MANAGEMENT STRATEGIES FOR RECURRING CONGESTION
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
2.0 FRE ways Management Strategies for Recurring Congestion

2.1 Freeway Flow Characteristics

Freeway traffic flow can vary from location to location, depending on factors such as lateral clearance, amount of truck traffic, design speed, weather, lane widths, weaving sections, terrain, and horizontal and vertical alignment. Figures 3 and 4 depict the relationship of freeway traffic flow under ideal conditions for various design speeds.

In Figure 3, freeways with 70 and 60 mile per hour (mp) design speeds have a capacity of approximately 2,000 passenger cars per hour per lane (pcphpl). This capacity value will vary in different areas. For example, at certain locations in San Diego, California, and Minneapolis, Minnesota, traffic volumes regularly approach 2,400 pcphpl. In fact, many areas are recording volumes higher than the traditional 2,000 pcphpl standard. Given that passenger cars are predominantly smaller compared to 30 years ago and the average motorist is a better driver, there is discussion in the industry that the typical freeway lane capacity is closer to 2,200 pcphpl. This value is currently being proposed for the updated edition of the 1985 Highway Capacity Manual. However, within this document, a freeway capacity value of 2,000 pcphpl is assumed.

The solid portion of the curve shown in Figure 3 is characteristic of stable traffic flow, while the dotted portion represents unstable flow. As freeway traffic volumes approach 2,000 pcphpl, the prevailing travel speed is reduced and, as volumes exceed this value, traffic conditions become highly erratic and unpredictable. The overall goal of freeway traffic management is to obtain a level of operation that provides stable traffic flow and maximizes the volume and speed of vehicles using the facility. To accomplish this goal, FMS strive to maintain traffic volumes on the stable portion of the curve, just prior to reaching capacity.

On the density-volume curves shown in Figure 4, the solid portion represents stable traffic flow and the dotted portion represents unstable flow. Figure 4 indicates that unstable traffic flow generally occurs when the density on the facility exceeds 60 vehicles per lane-mile. FMS strive to maintain traffic volumes below this value.

When freeway demand exceeds the above capacity values, an operational bottleneck is created that causes a traffic queue to form, resulting in freeway congestion. This phenomenon is conceptually represented in Figure 5, where the amount of delay incurred by motorists is represented by the shaded area. Through proper management of freeway traffic volumes, this area of the curve can be minimized.
Figure 3: Speed Flow Relationships Under Ideal Conditions
Source: 1985 Highway Capacity Manual

Figure 4: Density Flow Relationships Under Ideal Conditions
Source: 1985 Highway Capacity Manual
Figure 5: Relationships Among Demand, Capacity and Congestion

Source: Freeway Traffic Management, NCHRP 20-30
In the case of non-recurring congestion, this shaded area can usually be minimized through a special event or incident management program. Such a program can minimize the time spent in vehicles forming a queue (Ta to Tb) and the corresponding time necessary for the queue to dissipate. In the case of recurring congestion, existing freeway management techniques have not been able to completely minimize the shaded area of the curve because not all inputs to the freeway are controlled. Freeway on-ramps can be managed through various entry control strategies; however, freeway-to-freeway interchanges and the freeway mainline remain uncontrolled. Through proper management of all inputs, the delay represented by the shaded area can be reduced for all vehicles. A discussion of the different types of FMS and the various techniques associated with each strategy is presented below.

2.2 Freeway Management Control Strategies

Table 2 summarizes freeway management control strategies and the various techniques that can be employed to implement each. The main objective of these strategies is to improve the efficiency and safety of traffic flow through better management of the factors leading to congestion. The following sections describe the general operation of each technique, noting pertinent advantages and disadvantages. This discussion is not meant to be all encompassing, but should provide an introduction to the basic concept. For readers wanting more detailed information concerning a particular management technique, appropriate references are cited.

<table>
<thead>
<tr>
<th>Control Strategy</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance Ramp Control</td>
<td>Ramp Metering</td>
</tr>
<tr>
<td></td>
<td>Interchange Connector Metering</td>
</tr>
<tr>
<td>Priority Control</td>
<td>HOV Lanes</td>
</tr>
<tr>
<td></td>
<td>HOV Queue Bypass</td>
</tr>
<tr>
<td>Mainline Control</td>
<td>Overhead Lane Control Signals</td>
</tr>
<tr>
<td></td>
<td>Freeway Mainline Metering</td>
</tr>
<tr>
<td></td>
<td>Variable Speed Control</td>
</tr>
<tr>
<td>Congestion Pricing</td>
<td>SMART Corridors</td>
</tr>
<tr>
<td></td>
<td>Driver Information Systems</td>
</tr>
<tr>
<td></td>
<td>Peak Period Tolls</td>
</tr>
</tbody>
</table>

Table 2: Freeway Management Strategies and Techniques
Entrance Ramp Control

The purpose of entrance ramp control is to:

- Regulate the rate of vehicles that can access the mainline freeway so that traffic volumes do not exceed the facility’s capacity.

- Disperse platooning of vehicles merging on the freeway to minimize disruption to mainline traffic flow.

Ramp closure, ramp metering and interchange connector metering are the most common methods of entrance ramp control. Ramp closure (actually closing the freeway on-ramp on a temporary basis) is used only in extreme situations and will not be included in the following discussion.

Ramp Metering: Ramp metering uses traffic signal technology to regulate the rate of vehicles accessing the freeway. Ramp metering is a proven FMS that has been in existence for approximately 30 years. Since the first implementation in 1962 on the Eisenhower Expressway in Chicago, over 20 metropolitan areas in North America have installed ramp metering systems. Based on experiences in these areas, the advantages and disadvantages of ramp metering have become readily apparent.

Advantages

- **Reliability.** Ramp metering provides an improved, more predictable level of operation on both the mainline freeway and the on-ramp. The metered condition can properly distribute peak demand and facilitate the merge onto the freeway.

- **Increased Mainline Volumes.** Experience indicates that ramp metering will typically increase mainline traffic flow a minimum of five to six percent above pre-metered conditions. Certain areas have measured volume increases above 30 percent. Before and after studies conducted at one location in San Diego, California, indicated that mainline lane volumes increased to 2,600 pcphpl with the implementation of ramp metering.

- **Increased Mainline Speeds.** Minimizing the occurrence of congestion at the ramp entrance to the mainline translates to increased mainline speeds. Speed increases can vary depending on the location and extent of the ramp metering operation. Speed studies of areas with ramp metering systems have shown mainline speeds have increased anywhere from eight to 50 percent compared to the pre-metered condition.

- **Improved Safety.** Metering on-ramps to better manage congestion on the freeway mainline can reduce accidents at the ramp entrance to the mainline. Because an accident can cause a major reduction in vehicular throughput and a prolonged recovery
time, the improved safety aspect of ramp metering is a significant benefit. Some areas have estimated as much as a 40 percent reduction in accidents after implementing ramp metering.

- **Rideshare Incentive.** Providing an HOV bypass lane in combination with ramp metering can indirectly serve as an incentive to increase carpool formation. These eligible vehicles can bypass the queue formed by the single occupant drivers and either pass the metering point without stopping or also be metered, preferably at a faster rate. Seattle, Washington, has measured a 40 percent increase in the number of new HOVs accessing an on-ramp where a combined ramp meter/HOV bypass lane was installed.

- **Temporal Adjustments.** Ramp metering also induces some motorists to change the time of their trip. This temporal adjustment causes a more even distribution of vehicular travel (i.e., spreading the demand over the peak period as opposed to being concentrated in the peak hour).

**Disadvantages**

- **Diversion.** Ramp metering can potentially divert traffic that would have used the freeway to the arterial system. Though this result is undesirable in some instances, diverting trips from high volume problem ramps to other entry points and encouraging shorter distance trips to avoid the freeway may be desirable if alternate routes are underutilized. Some agencies argue that very short trips should not use the freeway, and diverting these trips is viewed by many as a benefit. In any event, the magnitude and impact of a diversion should be properly analyzed and addressed. A well-designed and operated ramp metering system can avoid a significant diversion to arterial streets.

- **Lack of Mainline Control.** Though ramp metering does help to improve mainline volumes and speeds, it is unable to optimize freeway mainline flow because not all inputs are controlled. Demand from freeway-to-freeway interchanges as well as the freeway mainline can cause congestion at various bottleneck locations (i.e., lane drops, many on/off-ramps) even with ramp metering. Until all inputs to the freeway are managed as a closed system, traffic volumes and speeds may often be lower than the freeway system is capable of achieving.

- **Ramp Queue.** Ramp metering will result in a queue forming behind the metering point which, in turn, could extend back to the local street. It is essential that proper analysis be conducted prior to installation of the meter to ensure that both queuing problems and excessive diversion do not occur. The backup onto the local street can usually be avoided by providing adequate vehicular storage and/or use of a detector placed near the local street to detect the queue (Figure 6). Experience has shown that, when the queue detector is activated, the ramp queue should not be completely flushed out into the freeway. Ramp metering rates should be gradually increased to reduce the queue.
Figure 6: On-Ramp Metering Configuration

The Equity Issue. One of the main arguments against ramp metering is that it favors long distance trips at the expense of shorter trips. For example, motorists living on the outskirts of an urban area may not experience ramp metering, or may have shorter metering rates, compared to motorists that live closer in. As the mainline becomes filled with more vehicles, more restrictive metering rates are typically needed to maintain an acceptable level of operation on the mainline. This condition can be reduced by maintaining relatively equal metering rates throughout the system, but this usually results in less than optimal performance at all locations. This dilemma may be more equitably resolved via mainline control, discussed later in this section.

As has been demonstrated, ramp metering is an effective traffic management strategy that can have a beneficial effect on mainline freeway traffic flow. Most of the ramp metering disadvantages mentioned above can be overcome with proper planning and design prior to installation. However, ramp metering alone cannot effectively optimize traffic flow on the freeway mainline.

Interchange Connector Metering: Interchange connector metering is a form of entrance ramp control that has been effectively expanded to better manage traffic flow at freeway-to-freeway connectors. These connectors serve as high volume inputs to a freeway and, in certain situations, can result in congestion on the mainline even with the application of local arterial on-ramp meters. For example, several areas have implemented ramp metering at on-ramps to relieve mainline freeway congestion. This strategy was very successful initially and, as travel demand increased, the metering rates were adjusted to accommodate the mainline flow. Eventually, the increase in freeway demand, combined with the unregulated traffic from interchange connectors, resulted in congestion returning to the freeway. This sequence of events illustrates how an uncontrolled freeway connector can eventually overwhelm the benefits achieved solely from ramp metering. Non-metered freeway connectors can lead to downstream congestion and merging problems similar to non-metered arterial on-ramps.

Interchange connector metering is accomplished using signals similar to ramp metering. Consequently, many of the advantages and disadvantages associated with interchange connector metering are similar to those of ramp metering. Advantages and disadvantages distinctive to interchange connectors are discussed below.

Advantages
• Regulates High Volume Connectors. Lack of control at high volume freeway connectors can result in congestion at the merge area of the freeway and the connectors. Proper control of high volume freeway connectors can facilitate the merge onto the freeway mainline and thus reduce congestion in the merge area.

• Improved Mainline Operation. Entrance control at freeway connectors removes the
congestion from the mainline to the connector, resulting in increased throughput, higher speeds, and reduced accidents on the freeway mainline. Connector metering operations in both Minneapolis and San Diego have demonstrated these benefits.

- **Lower Arterial On-Ramp Metering Rates.** Uncontrolled access at interchange connectors results in more vehicles on the downstream mainline requiring more restrictive metering rates at typical on-ramps to maintain the same level of service. Interchange connector metering can more equitably distribute delay to motorists accessing the freeway mainline.

- **Rideshare Incentive.** Similar to ramp metering, providing an HOV bypass lane, in combination with connector metering, can indirectly serve as an incentive to increase bus ridership and carpool formation. These eligible vehicles can bypass the metered queue of vehicles by either passing the metering point without stopping or being metered at a less restrictive metering rate.

**Disadvantages**

- **Connector Queue.** Regulating traffic flows on interchange connectors will result in a queue forming on the connector. Ideally, the design and operation of the connector meter should not result in the queue extending back to the upstream freeway. Providing additional queue storage capacity and/or a queue detector can alleviate this concern. In addition, advanced warning signs can be installed to warn motorists of the metering operation and help prevent rear-end accidents.

- **Multiple Metering of a Single Trip.** Depending on the location of interchange connector meters in relation to ramp meters, it is possible for a motorist to be metered more than once. The motorist may travel through a typical arterial on-ramp meter to ingress a freeway and then travel through an interchange connector meter if desiring to use another freeway. It is possible that motorists may alter their route and use local streets to minimize the number of freeway meters.

- **Political/Public Hurdles.** The idea of controlling traffic on the freeway mainline is not appealing to many individuals, including some transportation professionals, the general public and politicians. These opponents feel that the freeway is supposed to provide a high level of service without the typical traffic signals or stops associated with travel on the arterial street system.

- **Lack of Mainline Control.** The combination of connector and ramp metering will help to improve mainline volumes and speeds; however, these metering techniques may still be unable to completely manage freeway mainline flow because the mainline is not totally controlled. Though the above combination may be appropriate for certain situations, demand along the freeway mainline can still cause congestion at various bottleneck locations.
(i.e., lane drops, many on/off-ramps). Until all inputs to the freeway are managed, traffic volumes and speeds may continue to be lower than the freeway system is capable of achieving.

- **Existing Design Deficiencies.** The current configuration of many existing interchange connectors are not conducive to connector control. Geometric changes or upgrades may be necessary to provide needed storage requirements and maintain emergency vehicle response capability.

Interchange connector metering is currently being utilized in San Diego, Minneapolis, Seattle, San Jose and San Antonio. These areas have found connector control an effective control strategy that is accepted by motorists. Key to gaining motorist compliance is the realization by the driving public that connector metering benefits them. In each of the above areas, prior to implementation of the connector metering, mainline conditions were congested and motorists were experiencing significant travel delays. By improving freeway mainline conditions with connector metering, overall travel times were reduced and the number of accidents decreased. Motorists were willing to wait in the connector queue because when they reached the freeway mainline they experienced an improved level of service for the duration of the trip.

Connector metering in combination with ramp metering can provide greater control of the freeway system and, in certain situations, is sufficient to maintain an acceptable level of operation. However, in highly travelled freeway corridors, the above metering strategies may not be sufficient to effectively optimize mainline traffic flow because the mainline is not controlled.

**Priority Control**

The purpose of priority control on freeway facilities is to provide preferential treatment for HOVs such as carpools, vanpools, and buses. This preferential treatment is usually provided in the form of both travel time savings and increased trip time reliability compared to the more congested general purpose travel lanes used by single occupant drivers. These incentives can serve to induce more individuals to use alternate modes of travel and increase the passenger-carrying capacity of the freeway facility. Priority control techniques can take many forms, but are typically divided into two general categories: line-haul HOV techniques and HOV queue bypass techniques. The advantages and disadvantages associated with HOV facilities were the subject of an earlier Fellowship monograph by Charles A. Fuhs entitled *High-Occupancy Vehicle Facilities: Current Planning, Operation, and Design Practices*. Readers interested in more detailed information on this topic are encouraged to read this monograph.

HOV facilities have proven to be an effective means of preserving mobility in congested freeway corridors. They currently serve as a major component of freeway system mobility in...
congested areas such as Houston, Los Angeles, Seattle, and San Diego, and many more are currently under design. HOV queue bypass facilities combined with other FMS (ramp, connector and mainline metering) can provide additional travel time benefits for individuals who share a ride.

Though HOV facilities can provide a degree of mobility on the freeway mainline, they fall short of improving overall freeway operations for essentially three reasons:

- The success of HOV facilities is contingent on the existence of congestion in the general purpose lanes.
- HOV facilities primarily benefit individuals willing to share a ride; they provide minimal if any benefit to other users.
- HOV facilities do not provide any direct control of mainline operations.

Until freeway management techniques target all vehicles, freeway congestion will continue to exist, and the efficiency of the freeway system will continue to be less than optimal.

**Mainline Control**

The purpose of mainline control strategies is to regulate, notify and guide vehicles using the freeway mainline to obtain a more uniform, optimum and efficient flow of traffic along the freeway facility. The key difference between this strategy and entry and priority control strategies is that the control mechanism and resulting benefits are directed to all vehicles using the freeway facility. The control mechanism may be accomplished through several different techniques including overhead lane control signals, freeway mainline metering, and variable speed control. The definitions of each of these techniques and specific advantages and disadvantages are presented below.

**Overhead Lane Control Signals:** Overhead lane control signals usually display green or yellow arrows when a lane is open and red X’s or signal balls when a lane is closed. In many urban areas where there is a high directionality of traffic inbound in the morning and outbound in the afternoon (usually a minimum 65/35 split), reversible lanes are used to accommodate the directional demand and overhead lane control signals are used to indicate the direction of travel.

In the event of an incident, whether it is a traffic accident, special event or maintenance activity, overhead lane control signals can encourage vehicles in upstream lanes to travel around the incident. They may also be used to facilitate ramp or interchange connector merges by closing upstream lanes directly adjacent to the merging traffic (although this application is not currently being applied anywhere).
Overhead lane control signals are also used to regulate freeway mainline operation in tunnels. These signals are placed at the portal entry and within the tunnel to facilitate operations due to an incident or slow moving traffic within or downstream of the tunnel. A new application of overhead lane control signals is being evaluated in Dallas/Fort Worth and San Antonio, Texas, as well as Charlotte, North Carolina. Here signals are being installed at frequent intervals over each lane along a freeway or arterial. The impacts of this application have not been quantified.

The advantages and disadvantages associated with the application of overhead lane control signals are presented below.

**Advantages**

- **Lane/Incident Management.** Overhead lane signals can direct motorists to designated lanes as a means of improving traffic operation. This is particularly useful at toll plazas, tunnels and on reversible facilities.

- **Driver Warning.** Overhead lane control signals can alert motorists to a downstream problem. However, these signals provide limited (usually passive) information to the motorist and can be more effective when combined with other driver information systems, as is the case on Houston’s reversible transitways.

**Disadvantages**

- **Extensive Surveillance.** Overhead lane control signals would have to be implemented over an extensive area to efficiently manage the freeway lanes wherever an incident occurs. This requires active manual surveillance or complex detector algorithms to determine the conditions of the roadway and modify the overhead signals accordingly.

- **Weaving Difficulty.** Closing one or more downstream lanes can result in a situation where upstream traffic must weave or merge into fewer travel lanes. This creates an operational bottleneck at the lane control point and could increase the propensity for accidents.

Overhead lane control signals are an appropriate traffic control device for certain situations. Applied to reversible lane facilities, portal management for tunnels, bridge management, or directing traffic around incidents, overhead lane control signals can be very effective. However, as a congestion management strategy for addressing recurring traffic congestion, the traffic flow benefits of overhead lane control signals are limited.

**Freeway Mainline Metering:** Freeway mainline metering controls the amount of traffic entering a freeway segment to provide improved travel downstream of the control area. This control can be accomplished in different ways including specific geometric...
designs or overhead signals regulating when vehicles can enter into the control section (similar to ramp meter signals). Although freeway mainline metering can result in congestion on the freeway upstream of the control area, it may provide for an increase in traffic throughput downstream of the control area, an overall increase in travel speed and a net reduction in travel time throughout the project area.

The overall goal of this strategy is to regulate traffic so that the number of vehicles using the freeway is just under the capacity of the facility. If the demand exceeds the available capacity, then the freeway traffic flow becomes unstable and both freeway speeds and vehicle throughput are reduced. Controlling the amount of traffic entering the freeway mainline will result in the most efficient use of the available freeway capacity. There are a variety of other advantages that are provided through mainline control and these, as well as potential disadvantages, are noted below.

**Advantages**

- **Optimizes Freeway Efficiency.** Freeway mainline metering, used in conjunction with ramp metering and interchange connector metering, allows for control of all inputs to the freeway to potentially achieve the most efficient utilization of the available freeway capacity

- **More Equitable Freeway Control.** Controlling the mainline traffic eliminates the “Suburban Trip Preferential” argument that is associated with ramp metering (see ramp metering disadvantages). Freeway mainline metering can distribute delay to all vehicles in a more equitable manner, so that longer distance trips will not have an advantage over vehicles entering the freeway farther downstream.

- **Reduces Queue Backup on Downstream On-ramps.** To properly operate the freeway without freeway mainline metering, ramp metering rates are more restrictive causing ramp queues that often extend back to the arterial street. Excessive delay and lack of queue storage fosters complaints from citizens and local agency personnel, causing metering rates to be relaxed and vehicles entering the freeway at too high a rate, resulting in breakdown of the freeway mainline. However, the freeway mainline has virtually an unlimited queue storage capability and, if freeway mainline metering is properly used, it may not only distribute delay more equitably but also minimize the on-ramp queue storage problem.

- **Rideshare Incentive.** Freeway mainline metering used in conjunction with HOV queue bypass facilities can also indirectly serve as a ridesharing incentive. Providing an HOV queue bypass up to the mainline control point can allow eligible vehicles to bypass the mainline queue that forms during peak travel periods.
• **Bridge/Tunnel Management.** Freeway mainline metering has already been proven an effective mechanism to maximize throughput and maintain optimum operations at various tunnels and bridges. Examples include the Bay Bridge in San Francisco, the Baltimore Harbor Tunnel in Maryland and the Hampton Roads Bridge-Tunnel in Virginia.

**Disadvantages**

• **Mainline Queue.** Freeway mainline metering will result in a queue forming on the mainline upstream from the control point. This queue could be fairly lengthy, depending on the metering rate, number of lanes and travel demand characteristics. However, the potential downstream travel benefits through this control mechanism include higher speeds, lower travel times and increased throughput in the freeway corridor.

• **Rear-end Accident Potential.** The resulting mainline queue may increase the potential for rear-end collisions upstream of the mainline control point. However, appropriate advance warning signs can be used to minimize this possibility.

• **Political/Public Hurdles.** The idea of controlling traffic on the freeway mainline is not appealing to many individuals, including some transportation professionals, the general public and politicians. These opponents feel that the freeway is supposed to provide a high level of service without the typical traffic signals or stops associated with the arterial system.

• **Additional Lanes.** The maximum throughput of a metered lane is 900 to 1,200 vphpl using three- and four-second metering rates respectively, assuming a one-vehicle per green release pattern. With a two-vehicle per green release pattern, this throughput can be increased by approximately 200 to 300 vphpl. Ideally, it is desirable to meter the mainline where demand is less than 1,500 vphpl and thus minimize queue build-up and remove downstream congestion (see Chapter 4). However, in some situations, additional lanes may be necessary at the metering point to avoid overly restricting mainline flow.

• **Surveillance and Control Equipment.** Freeway mainline metering would likely require hardware implementation to properly manage and regulate the number of vehicles passing the mainline control point, and may require complex detector algorithms to determine changing roadway conditions.

• **Diversion.** Depending on the geometrics and characteristics of the traffic network, freeway mainline metering may divert unwanted trips to the local arterial system. This may not be locally acceptable.
Freeway mainline metering can serve as a means of controlling the freeway mainline to provide improved downstream travel conditions. Given a limited amount of mainline capacity, properly regulating mainline traffic flow can maximize downstream freeway operations and improve overall travel conditions along a freeway corridor. Without this mainline control, downstream travel speeds and volumes will be reduced as freeway demands exceed the facility’s capacity.

Though freeway mainline metering provides travel benefits, a major hurdle affecting more widespread implementation of this concept is negative reaction from public officials and the general public. It is perceived that the resulting traffic queue created upstream of the control point will provide additional delay that otherwise would not be experienced. This indicates that motorist education must emphasize that, in certain situations, freeway mainline metering can provide better driving conditions than if no form of mainline control were exercised.

**Variable Speed Control:** The intent of variable speed control is to optimize traffic flow on the freeway mainline by regulating the speed of vehicles on the facility. This can be accomplished with variable message signs displaying the speed limit motorists should maintain to provide safe and efficient driving conditions. To be effective, determination of the speed limit should be based upon real-time information (i.e., traffic volumes, densities, etc.) concerning freeway operating conditions. As traffic volumes approach the capacity of the freeway, regulating the speed limit can theoretically prevent traffic conditions from entering the unstable region of the speed/flow curve and attain the maximum vehicular throughput on the facility. Given that it is illegal to have speeds higher than the legal speed limit, variable speed control requires displaying speed limits lower than the traditional posted speed limit.

**Advantages**

- **Maintains Optimum Speed.** Variable speed control identifies the optimal speed vehicles should drive to achieve the maximum utilization of the available freeway capacity.

- **Maximizes Vehicle Throughput.** Providing motorists comply with the optimal posted speed limit, maximum traffic volumes will be achieved in response to the downstream approach conditions.

- **Advance Warning.** Appropriately placed variable message signs displaying the downstream speed limit provide motorists with an advance warning of a change in driving conditions. Motorists are then better prepared for the downstream travel conditions.
Disadvantages

- **Motorist Compliance.** Variable speed control relies primarily on voluntary compliance of the driving public to maintain the posted speed. Previous experience has indicated that motorists, seeing no reason to slow down, will exceed the optimum speed limit and drive as fast as conditions allow.

- **Enforcement.** To ensure motorists comply with the displayed optimum variable speed limit, extensive enforcement activities would be required. This can become an expensive effort given the level of enforcement necessary to ensure compliance and the complexity associated with enforcing a changing speed limit.

- **Lack of Mainline Control.** Variable speed control does not provide direct control of the freeway mainline. It provides a passive type of control relying primarily on voluntary motorist compliance.

- **Surveillance.** Variable speed control can require extensive surveillance capability and operational support to identify freeway conditions and determine the appropriate speed limit to display. This can be a significant operating cost.

- **Lack of Public Support.** The driving public will have difficulty understanding why they must drive at a reduced speed limit when there is no obvious reason.

In theory, variable speed control has the capability to more evenly balance travel conditions to minimize the occurrence of congestion. However, to be effective, travel demands must be within or near the capacity of the facility, and motorist compliance is essential. Variable speed control on the Lodge Freeway in Michigan, for example, met with unsuccessful results due to poor motorist compliance. From a practical consideration, motorists experiencing good travel conditions at 45 mph will inevitably increase their driving speed, causing travel conditions to deteriorate. Thus, variable speed control will provide little benefit to better manage freeway facilities where there is a significant amount of recurring congestion. However, when combined with driver information systems, variable speed control may be useful to manage traffic due to incidents or when approaching and travelling through tunnels.

Corridor Control

**SMART Corridors:** SMART corridors can be defined in many different ways and take on many forms, but the underlying principle is that they make better use of the available capacity within existing travel corridors. SMART corridors can include parallel freeways and/or one or more arterials. To effectively utilize the available capacity within these travel corridors, SMART corridors may employ some or all of the previously mentioned FMS, as well as other strategies that serve to integrate various FMS together into an auto-
mated system. Depending on the objectives of the operating agency, SMART corridors can be designed to address both recurring and non-recurring congestion. How “smart” a system is will depend on the level of investment that an area is willing to make and the level of FMS integration applied.

A SMART corridor is currently being developed in Los Angeles, California, encompassing the highly utilized Santa Monica Freeway (I-10) as well as several heavily travelled parallel arterials. The corridor being designed for this area will include a variety of traffic management techniques and state-of-the-art technologies to monitor and manage traffic flows, including the following elements:

- Monitoring and Control Capabilities:
  - SMART Corridor Computer Operating System
  - CCTV
  - Ramp and Interchange Connector Metering
  - Freeway and Arterial System Integration
  - Expert Systems

- Motorist Information Systems:
  - Variable Message Signs
  - In-vehicle Navigation Systems
  - Telephone Hotlines
  - Highway Advisory Radio
  - Teletext Services
  - Media Communications (commercial radio and television)
  - Digital Broadcasts

- Incident Management Capabilities:
  - Freeway Incident Management Teams
  - Arterial Street Incident Management Teams
  - Freeway Service Patrols

The above components represent a high-end SMART corridor system requiring a significant amount of hardware and personnel to operate. However, systems can be designed with fewer "bells and whistles" and still be considered a SMART corridor. For example, the INFORM (INformation FOR Motorists) system on Long Island, New York, is a SMART corridor that primarily utilizes variable message signs, ramp metering, CCTV, a TOC, and limited freeway/arterial street integration. INFORM does not include many of the components planned for the Los Angeles SMART corridor, though it is an extensive system that has provided improved traffic operations.
The following SMART corridor advantages and disadvantages discussion is not focused on each individual component, but on the general concept of SMART corridors.

**Advantages**

- **System Balance.** SMART corridors can maximize unused capacity in travel corridors to more equitably balance travel demands and improve the efficiency of the roadway infrastructure.

- **Real-Time Information.** Many of the components of SMART corridors provide motorists with current information concerning areas of congestion. Motorists can adjust their travel route based on the real-time information they receive from any of the motorist information techniques mentioned above.

- **Improved Response.** SMART corridors provide the operating agency or TOC with the ability to identify and respond more quickly to an area experiencing congestion. In the case of recurring congestion, operators can more readily adjust traffic signals or display messages warning of a problem area to more equitably distribute vehicle trips. In the case of an incident, SMART corridors allow for quick identification of the problem location, enabling incident management teams to be dispatched to reduce incident clearing time.

- **Multijurisdictional Signal Coordination.** SMART corridors allow for the coordination of traffic control devices over several jurisdictional boundaries.

**Disadvantages**

- **Implementation Cost.** Depending on the extensiveness of the SMART corridor, the amount of hardware required can become quite expensive.

- **Applicability.** SMART corridors are not applicable to every travel corridor. They require parallel facilities that provide excess capacity or that can feasibly accommodate additional traffic on occasion.

- **Multijurisdictional Boundaries.** In most instances SMART corridors will cross several jurisdictional boundaries (i.e., state, county, city). Coordinating with these various jurisdictions and reaching agreement regarding the type of system and how it operates within each area can present difficult political hurdles.

- **Alternate Route Surveillance.** Surveillance is also required on parallel facilities, whether they are freeways or arterials. This capability adds to the implementation and operating cost.
The SMART corridor concept is gaining attention and support from transportation professionals, public officials and the general public. The reasons for this widespread acceptance is that SMART corridors can provide motorists with information directing them to less congested routes, and technological improvements can allow for automated changes to ramp meters and traffic signal timing plans. In addition, the current definition of a SMART corridor does not contain any controversial traffic control elements that would restrict or regulate traffic operations (i.e., no direct mainline control capabilities). Thus, implementation is easier because the concept requires motorists to make travel adjustments in response to the information provided, rather than the local TOC having to direct control of vehicles on the freeway mainline.

Provided there is sufficient motorist compliance, SMART corridors can improve freeway operations due to recurring congestion. SMART corridors are also an excellent incident management tool provided the incident occurs within the general area covered by the corridor. The main hurdles with SMART corridors are associated with the extensive surveillance capability required, implementation costs, motorist compliance and jurisdictional cooperation.

**Driver Information Systems:** Driver information systems provide motorists with the most recent information regarding freeway operating conditions. With this information, motorists can make well-informed decisions concerning the remainder of their trip. For example, drivers may choose to remain on the freeway or exit the freeway and use an alternate route. The ultimate goal of driver information systems is to provide commuters with real-time information so that their trip-making decisions will improve overall traffic operations.

Essential to the success of driver information systems is the provision of accurate and concise information to allow commuters enough time to make travel decisions. Techniques currently used to transmit this information include variable or changeable message signs (VMS or CMS), commercial radio broadcasts, and HAR.

Presently, VMS are primarily based on traffic operators’ visual observations of freeway traffic conditions. Current research is addressing the possibility of automatically displaying messages based on electronically obtained surveillance information.

Given that a majority of motorists listen to the radio during their commute, commercial radio broadcasts are used as a means of relaying information. Radio stations usually have arrangements with TOCs to obtain the most recent information concerning freeway conditions, and they broadcast this data at regular intervals. In many areas, mobile (car) phones are being used as a means for the driving public to call the radio station directly and report on freeway conditions. Although the mobile phone technique can be useful, the reliability and accuracy of this information can vary substantially.
HAR can provide more detailed and reliable information for specific areas of the freeway system. HAR differs from commercial radio in that it uses either the high or low ends of the AM radio band to transmit information from low power roadside transmitters within a specific area.

Advantages

• **Current Freeway Status.** Motorists are provided the most current information regarding the operating condition of the freeway.

• **Flexibility.** Driver information systems provide motorists with the flexibility to alter their travel route, mode or time of their trip based on the message received.

• **Minimize Congestion.** Driver information systems can shorten the duration of congestion as a result of altering a commuter’s trip route in response to the displayed message. They provide a better distribution of vehicle trips to achieve system balance.

• **Advance Warning.** Appropriately placed driver information systems displaying pertinent messages can provide motorists with an advance warning of a change in driving conditions. Motorists are then more aware and better prepared for a change in downstream travel conditions.

Disadvantages

• **Information Reliability.** If information provided to motorists is not current and accurate, future messages will be ignored. A common complaint regarding existing systems is that they are not dynamic enough. For example, many times a displayed message states the occurrence and location of an incident, but is never updated. Motorists remaining on the freeway reach the incident location only to discover it has already been cleared. Consequently, motorists question the reliability of the system and the validity of future messages.

• **Surveillance.** Driver information systems require extensive surveillance capability and operational support to identify freeway conditions and display the appropriate message to the motorist. Surveillance is not only needed on the mainline facility, but on alternate routes as well. This can be a significant operating cost.

• **Overcompensation.** Driver information systems may sometimes be too effective, creating congestion on alternate routes and underutilization of the primary route.

Driver information systems are an effective means of communicating the status of the roadway system to potential users, but they do not provide a direct means of managing congested traffic conditions. However, they do provide indirect benefits by minimizing the
duration of congestion as drivers change routes to bypass bottlenecks. To attain more direct benefits, driver information systems should be combined with other FMS that offer more capabilities to better manage traffic. In this way, driver information systems can provide motorists with the reasons for the traffic management strategy being employed. If motorists understand why a particular measure is being taken, they will be more likely to tolerate or accept a minor inconvenience to benefit in the long run. Combining driver information systems with other FMS provides this capability.

**Congestion Pricing**

Congestion pricing involves the implementation of peak period roadway charges as a means of managing traffic congestion. This FMS is based on the economic perspective that motorists should pay the full cost of the congestion they create on the roadway system. Congestion pricing, from a transportation management perspective, attempts to spread demand to less congested segments of the network and less congested periods of the day. This strategy is very similar to many of our private services such as telephones, electricity, airlines and hotels in which users are charged higher rates during peak periods of demand compared to off-peaks. Congestion pricing can induce motorists to shift to alternate modes, drive during other periods of the day, or even reduce or consolidate trips of marginal utility.

The distinction between congestion pricing and toll roads is noteworthy. Toll road users pay tolls to offset the capital cost of constructing the facility as well as to finance the roadway’s operation and maintenance cost. Consequently, users will pay a toll anytime they use the facility. Congestion pricing strategies require motorists to pay a price for driving during the peak period in an attempt to better manage or redistribute congestion. Thus, it is possible to apply congestion pricing to toll road facilities.

The concept of congestion pricing actually originated in the United States in the late 1950s and became the subject of discussion in Europe during the 1960s. Interest in the United States was limited to economists within academic institutions. Only recently has there been renewed interest in considering congestion pricing as a transportation management strategy. Several areas overseas including Singapore, Oslo, Hong Kong, and Milan have implemented congestion pricing.

Singapore implemented an auto licensing form of congestion pricing in 1975 to discourage motorists from entering the central or downtown area during the morning peak period. Motorists are required to purchase a special permit/license costing approximately $2.50 per day and display it on their vehicle. This pricing strategy resulted in a significant reduction in the number of trips ingressing Singapore’s downtown area via automobile, from 56 percent to 23 percent. Subsequently, this pricing strategy was also extended to the evening peak period as well.
Oslo, Norway, implemented a similar system in the 1980s. Here motorists are required
to display a special permit to enter the central business district. Permits cost approximately
$1.50 per entry. Implementation of this permit system resulted in a seven percent reduction
in traffic within the CBD area. Revenues from this pricing strategy are applied toward high-
way improvements.

Milan, Italy, has implemented a peak period entry fee for vehicles desiring the central
area of the city. Its pricing strategy has resulted in a 50 percent reduction in the number of
vehicles entering the central area. Of the total vehicle reduction, 40 percent of the individu-
als shifted to public transit.

In 1986, Hong Kong conducted an experiment with automatic vehicle identification
(AVI). AVI technology enables vehicles to be automatically detected when passing a partic-
ular point and drivers are subsequently billed for the use of the roadway. Approximately
2,600 vehicles were equipped with this capability and the experiment was considered a
success technically. However, due to issues concerning privacy and the political environ-
ment at the time, this AVI operation was not implemented on a permanent basis.

Advantages

- Represents Actual Driving Cost. Congestion pricing more closely accounts for the
  actual cost of driving during peak periods because motorists are paying for the conges-
tion and air pollution they create. Congestion pricing can make drivers aware of the
real cost of driving a car, and encourage them to choose a more economical means of
reaching their destination (e.g., driving at a different time or using a different mode).

- Revenue Source. The use of peak period pricing can serve as an additional or substi-
tute revenue source to finance a variety of transportation improvements and/or to offset
any perceived hardship to low income motorists. One approach is to use pricing rev-
enues to upgrade transportation facilities in the same corridor, thereby giving low
income motorists an improved route option to reach their destination without having to
use the priced facility. In addition, if alternative fuels become predominate, congestion
pricing can represent a substitute revenue source for the gas tax.

- Transit Incentive. Congestion pricing can induce motorists to use other modes of travel
including bus, rail, vanpool or carpool. Operational strategies can be designed to allow
vehicles meeting person eligibility requirements to travel free of charge.

- Equity. Proponents believe congestion pricing is a more equitable, more effective and
less costly means of reducing congestion and air pollution compared to a regulatory
approach. For example, Southern California is employing a regulatory approach where
employers are being targeted to increase the average vehicle ridership of their employ-
ees. Congestion pricing can apply to all drivers, while a regulatory approach typically
singles out only employees who drive during the peak period. In addition, the operating and maintenance costs associated with enforcing the regulatory approach will become excessive compared to congestion pricing.

Disadvantages

• **Political Hurdles.** The most difficult challenge toward implementing congestion pricing strategies is overcoming political hurdles. Politicians fear that charging peak period tolls will put their area at an economic disadvantage by causing businesses to relocate to areas without congestion pricing. Although this phenomenon has not occurred in Singapore, Oslo or Milan, it may still be difficult to convince politicians in many United States cities.

• **Inelasticity.** There is a concern that vehicular demand for roadway travel is not sensitive to the cost of using the facility. It is generally expected that raising the cost for using a roadway will cause motorists to shift to other modes or postpone their trip to a different time period. However, limited United States experiences appear to indicate that vehicular travel is price inelastic.

• **Excessive Price.** Due to the price inelasticity mentioned above, it may require high charges for congestion pricing to function effectively. However, the political and economic ramifications of this approach will most likely preclude this option. It has been estimated that effective pricing strategies in California would require a charge of approximately 65 cents per vehicle mile traveled (VMT) (Orksi, 1992). Traditional toll facilities are currently priced at approximately 4 cents per VMT. Politicians are not likely to accept such a high charge given traditional toll prices.

• **Double Charging.** Many people will argue that motorists are being charged twice for completing their trip: once for the congestion price and once for the gas tax.

• **Existing Roadway Implementation.** Applying congestion pricing schemes to existing roadways will be difficult from both a political and operational standpoint. It may be more appropriate to apply this approach initially on new or toll facilities.

Using congestion pricing to better manage vehicles using the roadway infrastructure has been discussed, written about and debated for over 30 years. The strategy is quite simple, requiring motorists to pay a price equal to the cost associated with the congestion they create. Motorists will then be more aware of the cost associated with their trip and will only travel during peak periods when absolutely necessary. The result is less traffic during peak periods and improved travel conditions.

The feasibility of implementing congestion pricing is a difficult task. There are many
unresolved issues involved with implementing an areawide pricing strategy and the political/public hurdles associated with such a concept are immense. In reality, the probability of implementing areawide congestion pricing in the United States is rather remote at this time. The political environment is not prepared for prices to be applied to existing roadway facilities. Congestion pricing may first be applied to new highway construction or to single occupant vehicles using excess capacity available on HOV facilities. The above two approaches are currently being pursued in Southern California.

### 2.3 FMS Selected For Further Evaluation

The previous sections identified a variety of FMS capable of making better use of available freeway capacity. Some of these FMS have been in existence for a long time, while others have had very limited application. One goal of this monograph is to identify and further develop the FMS that have the most potential to better manage freeway mainline operations and benefit all vehicles on a freeway experiencing recurring congestion, while being capable of implementation within the next five years.

To assist in selecting the FMS that fall within the above goal, an ad hoc survey of leading technical specialists was conducted. The survey was distributed to individuals in geographic areas experiencing significant congestion (i.e., Houston, Los Angeles, Minnesota, New Jersey, etc.) as these areas are most likely to consider these types of solutions in the near term. Survey participants consisted of a cross section of individuals from state and federal agencies, transportation research organizations and transportation consultants. The survey consisted of five questions (shown in Appendix A) ranging from the need for more documentation concerning project development guidelines to the traffic flow benefits and implementation potential of each management strategy. The following five bullets summarize the survey results:

- The survey indicated that more documentation concerning planning, operation and design guidelines was needed for freeway mainline metering, congestion pricing, SMART corridors and interchange connector metering.

- Respondents identified ramp metering, SMART corridors and freeway mainline metering as having the highest potential to improve or better manage mainline traffic flow in the future. These were closely followed by connector metering, congestion pricing, driver information systems and HOV lanes.

- Although freeway mainline metering and congestion pricing were perceived to be very effective at better managing mainline operations, they were also perceived as the most difficult to implement. This indicates that more attention is needed towards addressing the marketing and political/public acceptance issues associated with these strategies.
• Assuming the implementation issue was solvable and appropriate planning, operation and design guidelines were developed, virtually all respondents indicated that they would use several of the listed FMS, indicating that no one strategy will solve the congestion problem. It can also be inferred that certain combinations of these FMS may be appropriate solutions for different situations.

• When survey respondents were asked to rank the three FMS with the most potential for improving or better managing mainline traffic flow, ramp metering received the most votes. A distant second was freeway mainline metering, closely followed by HOV lanes, congestion pricing, SMART corridors, driver information systems and connector metering.

Sufficient documentation and experience already exist for local street ramp metering, driver information systems and HOV lanes. Consequently, these three strategies will not be carried forward. For more information on these FMS, consult the references cited in the bibliography.

The remaining FMS deemed beneficial by the ad hoc survey include freeway mainline metering, congestion pricing and SMART corridors. However, a detailed evaluation regarding the congestion management potential of all three FMS would be beyond the scope of this undertaking. Consequently, only freeway mainline metering will be carried forward and analyzed with a more detailed and quantifiable approach. This decision has to do with the level of research currently being pursued by others in the profession.

SMART corridors are gaining much attention because systems can be designed based upon the level of funding available and are not controversial from a political or public perspective. One ongoing case study evaluation is being conducted for the Santa Monica Freeway SMART corridor and similar evaluations are being performed for the INFORM corridor in New York. Information resulting from these studies will be used to develop general guidelines when considering SMART corridor applications. Consult the bibliography for existing references.

Congestion pricing has recently experienced a rebirth of interest as both a means of managing congestion and as a potential solution to a growing air quality problem. The level of congestion now facing many urban areas across the country, combined with the diminishment of traditional funding sources and a growing awareness of the environmental consequences of widening existing facilities, has made congestion pricing a more palatable solution to many professionals. As part of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) the FHWA formed a Congestion Pricing Pilot Program that authorizes a maximum of $25 million for fiscal years 1992 to 1997 for the development, operation and
evaluation of up to five congestion pricing demonstration projects. As a result of this pro-
gram, considerable attention and research has been and will continue to be conducted for
congestion pricing.

Contrary to both SMART corridors and congestion pricing, attention to freeway mainline
metering is virtually nonexistent. With the emergence of IVHS, the surface transportation
system is envisioned to operate at a much improved level of efficiency. IVHS will take
advantage of technological improvements to ultimately provide users and operators with a
more reliable and efficient highway system. It can also facilitate freeway mainline metering
by providing the capability to control mainline traffic to maintain a desired level of service.
One of the primary reasons mainline control has had limited application thus far are percep-
tions that mainline control will worsen freeway conditions and be met with negative reaction
from public officials and the general public. Both of these issues are addressed in this
research. In addition, properly implemented mainline metering systems may enhance the
anticipated benefits of IVHS elements as they come on-line.
3.0 MAINLINE METERING
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
3.0 MAINLINE METERING

Control systems have substantially improved operations on many freeways, but even the most sophisticated systems have failed to eradicate congestion and ensure optimal operation. Previous discussion focused on the fact that not all inputs to the freeway are properly managed. Until they are, including the freeway mainline, freeways will continue to be susceptible to gridlock conditions. This chapter explores in greater detail the merits of freeway mainline metering as a means of better managing freeway traffic congestion.

3.1 The Mainline Metering Concept

Freeway mainline metering involves controlling the amount of traffic entering a freeway segment to provide improved travel downstream of the control area. This can be accomplished in a variety of ways including specific geometric designs or lane use signals regulating when vehicles can proceed into the control section (similar to ramp meter signals). Although freeway mainline metering may result in congestion upstream of the control area, it allows for increased vehicle speeds downstream and, in certain situations, may provide an overall net reduction in travel time and an increase in downstream traffic volume.

Other traffic management measures can be combined with mainline metering depending on the overall objectives desired. For example, HOV lanes can be incorporated upstream of the metering location to allow eligible vehicles to bypass the congestion in the general purpose lanes. This approach will provide eligible vehicles with a travel time advantage over the adjacent general purpose lanes, encourage more people to share a ride, reduce the number of vehicles desiring the facility, and move more people through the control section.

Due to the upstream queue that will occur with mainline metering and the ensuing concerns of both the general public and local politicians, mainline metering should only be considered under the following special conditions:

- There should be congestion on the freeway. If there is no congestion, there is no need to employ a metering strategy. In general, mainline metering can be considered when there is a bottleneck that causes vehicular demand to exceed the capacity of the freeway.

- The proximity and accessibility of parallel routes should also be considered. Allowing vehicles to easily bypass the metering operation via the local street system may defeat the purpose of the management strategy.
• Within the control section, ramp metering must be utilized on all on-ramps to properly manage all vehicles accessing the freeway system and maintain the desired operating condition on the freeway. For a typical urban freeway, mainline metering alone will not be sufficient to improve overall traffic operations. Ramp and connector metering are necessary and integral to the viability of mainline metering.

Further and more detailed planning, operational and design considerations are presented in Section 4.0.

3.2 Previous Mainline Metering Experience

To date there has been no application of mainline metering on a typical urban freeway system. However, this concept has been applied successfully to bridges and tunnels and, to a limited extent, to freeway-to-freeway connector movements. Some examples include the San Francisco-Oakland Bay Bridge in Northern California, the Hampton Roads Bridge-Tunnel in Southeastern Virginia, and freeway-to-freeway metering in San Diego, California, and Minneapolis, Minnesota.

Bay Bridge

The Bay Bridge traffic management operation in Northern California is an example of how mainline metering can be employed to increase downstream traffic volumes. The Bay Bridge is one of the few links across the San Francisco Bay that connects the cities of San Francisco and Oakland. Figure 7 illustrates the general lane configuration of the Bay Bridge metering system. During the AM peak period, three freeways converge onto the Bay Bridge to San Francisco. This traffic passes through a 17-lane toll plaza, of which two lanes are reserved for HOVs throughout the day. During the peak period two additional lanes are also reserved for HOVs. Approximately 1,000 feet downstream of the toll plaza a metering bridge regulates the frequency of vehicles approaching the five lanes that cross the bay. HOV vehicles do not pay a toll and may travel through the metering area without stopping. Prior to the metering operation, downstream throughput on the bridge averaged approximately 8,200 to 8,300 vehicles per hour (vph). Implementation of the mainline metering resulted in downstream throughput on the bridge averaging 9,500 vph and sometimes even approaching 10,000 vph. Thus, the metering system employed at the Bay Bridge increased downstream traffic volumes by 15 percent.

In this example, the Bay Bridge serves as a bottleneck for commuters emerging from the three freeways and desiring to cross the San Francisco Bay. Without mainline metering, the Bay Bridge experiences a drop in capacity. However, by managing the amount of traffic entering the bottleneck section, vehicle throughput on the bridge is increased.
Figure 7: Mainline Metering, Bay Bridge, San Francisco
Hampton Roads Bridge-Tunnel

The Hampton Roads Bridge-Tunnel is one of Southeastern Virginia’s most important facilities, providing the only interstate link across the Hampton Roads Harbor. Each of the two tunnels is approximately 7,300 feet in length with double trestles of approximately 3,225 feet on the northern approach and 6,000 feet on the southern approach. The combination bridge-tunnel-bridge connects the Hampton shore on the north to the Norfolk shore on the south. By July 1983 delays of up to two hours were experienced, causing cars to overheat and increase carbon monoxide (CO) levels within the tunnel. In August 1983, manually controlled mainline metering was initiated. This consisted of stopping traffic prior to the tunnel entrances when the vehicles within the tunnel slowed to 15 mph or less. When the tunnel was clear of traffic and the CO levels dropped, the traffic was released. In all cases, the vehicles that had been detained caught up with the vehicles that had not been detained before they reached the opposite shore. In effect, motorists who had been detained five to eight minutes prior to entering the tunnel arrived at the same time that they would have if they had not been detained. Several benefits were derived from this form of mainline metering including:

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

This form of mainline metering was found to be one of the most effective methods of managing the bridge-tunnel-bridge traffic during periods of heavy congestion.

Baltimore Harbor Tunnel

In the 1970s, the Department of Civil Engineering at the University of Maryland initiated a project entitled “The Study of Traffic Flow on a Restricted Facility.” This study, sponsored by the Maryland State Highway Administration and the Federal Highway Administration, utilized the Baltimore Harbor Tunnel as a test bed to analyze the concepts of traffic flow theory. The Baltimore Harbor Tunnel serves as a link along I-95, which is one of the busiest interstate facilities in the northeast, if not the country. Achieving the optimal utilization and efficiency approaching and within the tunnel, in terms of vehicular throughput, quality of traffic flow and improved safety were of principal concern in the study.

One of the control strategies analyzed was the effects of a pre-timed mainline metering system upstream of the entrance to the tunnel and downstream of the tunnel toll plaza. Traffic signals were located approximately 1,200 feet upstream of the tunnel portal and pre-timed metering scenarios for cycle lengths of two, three and four minutes were evaluated. When metering was engaged, the red time varied between seven to 10 seconds and amber time was between three and five seconds. The signals were only activated when traffic was
congested from the tunnel portal to the merging area just downstream of the toll plaza. This corresponded to vehicular speeds of 20 to 25 mph as motorists passed the metering point. When the metering was not engaged, the signals were a continuous green.

As shown in Table 3, the metering operation resulted in increased speeds within the tunnel bottleneck, in addition to an increased flow rate within the tunnel. Table 3 also shows the percentage of speeds higher than 32 mph, defined in the study as the uncongested state. The 120-second cycle provided the best level of operation from a traffic flow standpoint, experiencing “study defined” uncongested conditions approximately 63 percent of the time. Based upon a speed-flow curve developed from the above data, the study noted that the metering system has the potential to increase the capacity per lane by about 10 percent above the no-control condition.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Mean Hourly Flow Rates (vph)</th>
<th>Increased Flow Over No-Control (vph)</th>
<th>Mean Speed (mph)</th>
<th>Increased Speed Over No-Control (mph)</th>
<th>Percent of Speeds Over 32 mph (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Control</td>
<td>1388</td>
<td>—</td>
<td>21.9</td>
<td>—</td>
<td>1.0</td>
</tr>
<tr>
<td>120-Second</td>
<td>1493</td>
<td>109</td>
<td>24.2</td>
<td>12.3</td>
<td>62.6</td>
</tr>
<tr>
<td>160-Second</td>
<td>1469</td>
<td>81</td>
<td>26.6</td>
<td>4.7</td>
<td>27.6</td>
</tr>
<tr>
<td>240-Second</td>
<td>1366</td>
<td>-22</td>
<td>19.6</td>
<td>-2.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 3: Comparison of Mean Flow Rates and Mean Speeds*, Baltimore Harbor Tunnel

* Left lane within tunnel

**Freeway-to-Freeway Metering, San Diego**

In San Diego freeway-to-freeway metering has been used successfully at two specific locations shown in Figure 8. This figure illustrates that State Route (SR) 67 provides three travel lanes prior to transitioning down to one lane and merging with I-8 into downtown San Diego. Prior to implementation of the connector meter, there were long delays and traffic queues both on SR 67 and on the I-8 mainline. With the metering system in place, free-flow operations are maintained on I-8 and the travel time on SR 67 is reduced. Although a traffic queue forms upstream of the metering location, commuters remember the poor traffic conditions prior to the metering system and are willing to wait. The SR 67 queue, sometimes reaching two miles in length, is more of a rolling queue with vehicles rarely coming to a complete stop. The metering operation allows two cars per lane to pass through the meter during each green cycle, and the green indication for each lane is staggered.
Figure 8: Connector Metering Examples, San Diego, California
The effectiveness of the metering operation was indirectly demonstrated several years ago when an electrical malfunction caused the meters to discharge vehicles more rapidly onto I-8 compared to the normal metering rate. Vehicle queues extending up to several miles formed on I-8, in addition to the queue on SR 67. Although this was not a planned occurrence, it served to educate the public to metering benefits and as a reminder of the conditions that existed prior to the metering operation.

The second configuration shown in Figure 8 illustrates a similar operation for the SR 94 and SR 125 freeways. To maintain free-flow operations on the SR 94/SR 125 mainline, a mainline/connector meter is used to regulate vehicles entering the mainline from SR 94. As shown in this figure, the operation also contains an HOV bypass lane that provides a travel time benefit for those motorists willing to share a ride. All three lanes are metered as well as an on-ramp that also accesses the mainline. No safety problems have surfaced as a result of the metering operation. Queues extending on the connector existed prior to installation of the metering control strategy.

When the SR 94/SR 125 connector meter was first activated, peak hour traffic volume was approximately 1,900 vph with an average wait of approximately one minute and a maximum wait of three minutes. Today the peak hour volume is near 2,900 vph and the maximum wait can exceed 10 minutes. Even with these delays, motorists have expressed very few complaints. Public acceptance has remained high largely due to the improved speeds maintained on the freeway mainline downstream of the metering point. Time savings of up to 20 minutes have been experienced for some commuters with the metering in place.

Though the two San Diego examples are referred to as freeway-to-freeway metering, they really represent freeway “mainline” metering. At each location all mainline lanes on the state highway freeway facility are metered. These mainline metering operations function effectively for several reasons:

- The freeway mainline provides a virtually unlimited amount of queue storage (unlike typical freeway on-ramps)
- There are not any convenient parallel routes that bypass the metering operation
- Local commuters realize that the metering operations will provide improved traffic flow downstream and have accepted the concept

Freeway-to-Freeway Metering, Minneapolis

To date, Minneapolis-St. Paul has the largest number of freeway-to-freeway meters in the country. The Minnesota Department of Transportation (MNDOT) first instituted freeway connector metering in 1971, and presently has 50 connector meters implemented throughout the Minneapolis-St. Paul area. In most instances, MNDOT has implemented the metering in conjunction with other roadway improvements. It is interesting to note that MNDOT,
in addition to using connector metering to improve traffic flow on the mainline at freeway interchanges, also uses freeway connector metering to encourage route diversion. Minneapolis also has several high volume freeway connectors that handle a disproportionate amount of volume compared to nearby facilities. As such, MNDOT places a great deal of emphasis on identifying feasible alternate routes and using connector metering to facilitate route diversion. MNDOT has performed several studies to quantify the benefits of connector metering as part of an overall metering system and has estimated that, on average, there is an increase in downstream throughput of 300-400 vphpl, increases in speed of approximately 27 percent, and a nearly 40 percent reduction in total accidents. These benefits would not have been possible without the freeway connector meters.

Unregulated Examples of Mainline Metering

Most commuters experience mainline metering without realizing it. Regulated mainline metering exists when overhead lane use signals, similar to ramp meter signals, provide red and green indications to motorists. The purpose of a mainline meter is to regulate the number of vehicles entering a freeway section to improve downstream travel conditions. Mainline metering is also achieved in an unregulated fashion as a result of either a freeway incident or a reduction in freeway capacity (a lane drop).

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

Another form of unregulated mainline metering occurs where there is a reduction in downstream capacity. Consider a four-lane freeway that has a lane drop resulting in a three-lane facility. If the four-lane freeway is operating near capacity, the lane drop will serve as a bottleneck. As the freeway approaches capacity, a queue usually forms upstream of the bottleneck as vehicles maneuver into the three downstream travel lanes. Downstream of the lane drop, traffic conditions are usually better than upstream. The lane drop essentially functions as a mainline meter. However, as a result of vehicles maneuvering into the three lanes at the bottleneck location, downstream vehicular throughput is reduced to less than what could be achieved. This situation is analogous to the Bay Bridge and San Diego (SR 67) situations. In each case there was a reduction in downstream capacity that limited the number of vehicles that could travel through the bottleneck.
However, once the mainline metering system was implemented, downstream vehicular throughput increased.

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

### 3.3 Mainline Metering Research Objective

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

During periods of heavy congestion, traffic volumes on the freeway can approach and exceed 60 vehicles per mile per lane (vpmpl). This results in the freeway operating in the unbalanced portion of the density-flow curve and a corresponding reduction in traffic flow efficiency. Figure 9 illustrates that this traffic flow reduction can also be considered a reduction in capacity. In Condition 1, where capacity exceeds demand, there is no congestion and traffic flows smoothly. As demand builds to equal capacity, unstable flows are experienced, and inefficient operation takes place. Finally, a “breakdown” occurs and traffic flows fall sharply. This reduction in traffic flow can be referred to as the operational capacity due to unstable flow. Under Condition 2, operation is unstable, inefficiencies continue to bring about a loss in capacity, flows drop off accordingly, and congestion persists. This trend continues until a rebalancing of the capacity/demand relationship takes place. The operational capacity approaches the actual capacity and stable flow with no congestion is restored (Condition 3).

A review of traffic flow on several freeways under varying congestion conditions in California has revealed that freeway efficiency was reduced in some cases by as much as 50 percent as congestion set in, falling from a free-flow rate of 1,800 to 2,000 vphpl to, in the most extreme case, a flow of about 1,000 vphpl under stop-and-go operation. Traffic flow losses in the 25 to 30 percent range were not uncommon. If the conditions leading to “breakdown” could be avoided (i.e., the capacity/demand balance could be maintained), congestion would be minimized, and operational capacity due to unstable flow would not
Figure 9: Traffic Flow or Capacity Loss Due to Congestion
materialize. In effect, the traffic flow/capacity loss would be preserved, or added back into the system, to serve greater traffic demands.

The traditional freeway management response to preventing a breakdown has been to institute ramp metering to regulate the entry of vehicles onto the facility. Ramp metering has been proven to be a very successful strategy and has been used to maintain freeway operations in the balanced portion of the density-flow curve. However, when freeway-to-freeway connectors remain uncontrolled, large traffic volumes have access to the freeway. Consequently, during peak travel periods, the freeway facility can again enter into the unbalanced portion of the speed-flow curve.

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

Assuming that both typical on-ramps and freeway connectors can be metered, the only input that remains uncontrolled is the freeway mainline. One objective of this study is to determine if mainline metering for the non-bottleneck condition can provide traffic operational benefits beyond those achieved from ramp metering. Due to the uncertainty and expense of field experimentation, traffic flow was modeled through computer simulation. The INTRAS program was selected for this purpose. Detailed explanations of the simulation methodology, study area network, and results are provided in Appendix B. A summary of these results follows.

### 3.4 Mainline Metering the Non-Bottleneck Condition

**Introduction**

In the absence of a bottleneck, freeway traffic flow is usually tolerable to everyday commuters and operators throughout most of a typical day. Though the definition of “tolerable” may vary in different areas, a state of equilibrium is usually reached when both the operator and the user are satisfied with freeway traffic conditions. However, during peak periods when travel demand often exceeds the capacity of the freeway facility, traffic conditions become increasingly more congested, causing commuters to spend more time in gridlocked conditions.
Previous sections have documented how mainline metering has improved traffic conditions by regulating the number of vehicles entering a bottleneck section. For non-bottleneck locations where vehicular demand exceeds freeway capacity, mainline metering might also be used to improve downstream travel conditions. The purpose of this research is to determine if mainline metering is able to increase downstream throughput and vehicular speeds and possibly reduce overall travel time through a non-bottleneck freeway section.

By metering the mainline to limit the number of vehicles that can be optimally accommodated given the downstream capacity and ramp volumes, travel delays traditionally incurred when vehicles are maneuvering into a freeway section of reduced capacity may be eliminated. It is important to discern if this mainline metering hypothesis can provide additional benefits over and above typical ramp metering. To evaluate these potential benefits, freeway volumes ranging from mildly to heavily congested, together with various ramp metering and mainline metering rates, were simulated along a typical freeway segment.

**Summary of Results**

The purpose of the simulation runs was to determine if there are any freeway operational benefits above those achieved through ramp metering that can be attained by metering the freeway mainline for the non-bottleneck condition. Several inferences can be drawn from the results presented in Appendix B:

- As the freeway mainline volume increases, ramp metering appears to increase the downstream vehicular throughput by approximately two to four percent. This result is basically consistent with existing experiences with ramp metering to date.

- Ramp metering appears to increase the freeway speed and the average speed for the entire freeway network compared to the no-control scenario. In addition, the more restrictive the metering rate, the better level of operation on the freeway (in terms of higher speeds and lower travel times).

- Combining mainline metering with ramp metering resulted in the same or, in several cases, slightly higher downstream vehicular throughput compared to the no-control and ramp metering alone scenarios.

- As mainline service volumes increase, the freeway speed for the ramp metering alone scenario decreases. The addition of mainline metering provides much improved freeway conditions downstream of the mainline meter. This improvement is balanced by the added travel time incurred upstream of the mainline meter.

- When mainline metering is combined with ramp metering, the average freeway speed
for vehicles originating upstream of the mainline meter remains unchanged. However, the freeway speed downstream of the mainline meter increases.

- Vehicles originating from on-ramps downstream of the mainline meter are provided better freeway conditions compared to the no-control and ramp metering alone scenarios. Consequently, vehicles originating from these downstream on-ramps experience lower freeway travel times.

These results appear to indicate that mainline metering can provide improved freeway operations downstream of the metering point compared to the ramp metering alone scenario. For mainline service volumes of 1,950 vpl, the average freeway speed downstream of the mainline meter was 22 percent higher than the ramp metering alone scenario. But, most important, the simulation indicates that this can be accomplished without increasing freeway travel time. This is an important observation considering that one of the concerns regarding mainline metering has been the perception of additional delay incurred by vehicles waiting in a mainline queue upstream of the mainline meter. From these results, it appears that this delay is balanced by improved freeway operations downstream of the mainline meter. Based on the San Diego metering experience, commuters are willing to wait in a queue (in San Diego’s case it is more of a rolling queue) provided they perceive an improvement in their trip further downstream.

The results are also important when considering the equity issue. One of the historical arguments against ramp metering has been that vehicles originating from entry points closer to their destination incur a greater travel time delay than vehicles originating farther out in the suburbs. Based on this research effort, it appears that mainline metering may not increase the overall travel time through the freeway network, and may be used to more equitably distribute the delay incurred by vehicles ingressing the freeway. For example, consider the morning commute of a line-haul freeway approaching the outskirts of a metropolitan area. A mainline meter may eliminate the need to meter on-ramps upstream of the mainline meter location. The delay experienced by commuters using this particular freeway could be equitably distributed between the mainline meter and metered on-ramps downstream of the mainline meter.

This research seems to indicate that, depending on the goals and objectives of the freeway operating agency and given the right conditions, mainline metering may serve as an appropriate freeway management tool.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
4.0 DEVELOPMENT OF A FREEWAY MANAGEMENT SYSTEM
4.0 DEVELOPMENT OF A FREEWAY MANAGEMENT SYSTEM

This chapter addresses a potential application of systemwide freeway management. The following discussion is based on managing freeway demand as a closed system to maintain the optimum number of vehicles on the highway system before a breakdown occurs. This approach has been used by utility companies for some time. For example, electrical companies know the amount of current that can be carried in their power lines before the lines break down. When electrical demands exceed the amount of current that can be accommodated, the utility either reroutes or delays service until there is room, or available capacity, to send the electrical current. In the same manner, if the volume of traffic entering a freeway section can be maintained just below the section's capacity, the most efficient utilization of the roadway can be achieved.

4.1 An Application of Systemwide Freeway Management

For illustrative purposes, a typical morning commute period is considered below, and a schematic of this systemwide freeway management approach is illustrated in Figure 10. In this figure, trips originating in the suburbs enter the freeway via uncontrolled on-ramps. Ramp metering is not necessary in this area since there is limited volume on the freeway mainline. As these suburban trips approach the outskirts of the metropolitan area, they encounter the mainline meter, which results in a slow rolling queue as vehicles approaching the metering point prepare to stop. HOV bypass lanes are provided when necessary to offer eligible vehicles a travel time benefit approaching the mainline meter. HOV lanes are not required downstream of the metering point since mainline metering ensures that the freeway is operating at a high level of service. Downstream of the mainline metering point arterial on-ramps are metered to avoid platooning of vehicles entering the freeway. Freeway-to-freeway connectors are also metered to ensure that all inputs are properly managed and the freeway operates as a closed system.

Vehicles queuing from the on-ramps onto arterial streets, due to high demands or lack of on-ramp storage, may reach unacceptable levels, thus requiring the operating agency to relax various on-ramp metering rates to allow more than the optimum number of vehicles onto the freeway. As a result, the freeway mainline may again experience congestion, perhaps seven, ten or 15 miles downstream. To mitigate this resurgence in freeway congestion, another mainline meter would need to be implemented. Vehicles would slow down into the rolling queue that forms when approaching each mainline meter. HOVs could bypass this queue and gain a travel time benefit via the HOV bypass lanes if such were provided.

In theory, metering would start in areas where traffic demand is fairly low, possibly 1,500 vehicles per hour. Motorists would encounter a mainline meter signifying the begin-
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
ning of the freeway management system. Downstream of the first mainline meter, all subsequent on-ramps and freeway connectors would be metered to ensure that the freeway operates as a closed system. As motorists enter a highly developed urban area, subsequent mainline meters would be used to maintain freeway volumes at an acceptable level of service. These subsequent meters may have increasing metering rates (1,700, 1,800 or 1,900 vphpl) to accommodate the increased traffic volume destined for the urban area. However, the mainline and ramp metering rates would be designed to manage traffic at the freeway’s highest efficiency, i.e., just below the capacity of the facility.

The afternoon commute period could be managed in a somewhat similar fashion. Commuters leaving their place of employment would ingress the freeway via metered on-ramps. Metered on-ramps at the beginning of the outbound commute would be necessary since there would already be a substantial number of vehicles on the freeway. As the combination of mainline and on-ramp volume results in congestion, a mainline meter would be implemented to improve downstream travel conditions. Successive mainline meters could then be implemented as necessary.

The following performance characteristics can be expected with the above systemwide mainline metering strategy:

- Mainline meters may be located at 8- to 15-mile intervals. Within these intervals, vehicles using the freeway will experience non-congested conditions.

- HOVs could still gain travel time benefits via bypass lanes provided at the mainline meters.

- Depending on the amount of additional lanes provided at the mainline meter, queue lengths from a quarter mile up to two miles may occur.

- Overall travel time for vehicles entering the freeway from non-metered ramps (ramps external to the controlled freeway section) would be the same as without the mainline meters.

- Overall travel time for vehicles entering from metered ramps would be slightly reduced since they will now be entering a mainline freeway experiencing non-congested conditions.

This freeway management system is one plausible means by which mainline metering can be considered on a systemwide basis. Given that the simulation results presented in Section 3.4 indicate that a mainline meter can result in improved freeway conditions down
stream of the metering point and, even with the resulting upstream queue still maintain and, in some cases, reduce overall travel time, the above approach may be viable.

There remain several planning, operational and design issues that must be addressed before this type of freeway management system can be successfully implemented. These considerations, presented below in question form, should be investigated as individual white papers. Although suggested solutions are presented, further research is needed to verify and substantiate these ideas.

Freeway Management System Planning Considerations
1. Should mainline metering be considered before ramp or connector metering?
   Ramp and connector metering are prerequisites of mainline metering for a typical urban freeway environment. Mainline metering should only be considered after ramp and connector metering are in place. In many cases, ramp and connector metering may be sufficient to improve freeway operations. If significant congestion still occurs, implementation of mainline metering can then be considered. Control of all freeway inputs downstream of the mainline meter is essential to maintain the desired freeway operating condition and minimize the route diversion potential of motorists attempting to bypass the mainline meter.

2. How should jurisdictional issues be addressed?
   The proposed freeway management system requires that mainline volumes be maintained below the freeway’s theoretical breakdown capacity. To accomplish this, mainline meters are located both within and at the outskirts of an urban area. The outlying areas may question why the mainline meter is creating a mainline queue that would not otherwise exist within their local jurisdiction. These jurisdictions will ask, “Why does the mainline meter have to be in our area? Why not in someone else’s jurisdiction?” Addressing these questions and educating outlying areas on the benefits of a freeway management approach is essential if implementation is to be achieved.

3. How should institutional issues be addressed?
   Who or what agency should be responsible for pursuing implementation of this freeway management strategy? Is a champion necessary? What should the decision process be? Is a legislative action required/needed? These and other institutional issues affecting implementation are partially addressed in Chapter 5. Overall, this approach has not yet been tested and there needs to be a demonstration project in an area that has a “willingness to try” an innovative approach to better manage areawide traffic congestion.
4. **What should be the distance between successive mainline meter locations?**

The interval spacing between mainline meters should vary depending on local conditions such as traffic demand and orientation of other entry points. Is there a minimum spacing distance that should always be adhered to? Five miles, eight miles, ten miles?

5. **Should HOV bypasses be incorporated into the metering operation?**

Whenever there is sufficient demand to warrant an HOV bypass, it should be implemented concurrently with mainline metering. The HOV queue bypass will enable eligible vehicles to bypass the queue upstream of the mainline meter. HOV bypasses can induce ridesharing and increase the person movement of the bridge and/or tunnel. A general rule of thumb for the minimum volume needed to consider HOV bypasses is 120 vph.

6. **What is necessary for public/political acceptance?**

Educating the public, political officials and even transportation professionals is essential if the mainline metering component has any chance to succeed. A mainline metering operation that is successful technically may fail if a positive constituency has not been built prior to implementation. Alternative means of gaining public and political support are discussed in Chapter 5.

7. **What are the air quality issues/improvements?**

Providing improved travel conditions on the freeways through a freeway management system should result in better air quality and could provide the impetus to consider this type of approach. Would the mainline meters create isolated “hot spot” locations? Would this be any different from the gridlock conditions that may be experienced without this type of freeway management approach? These considerations need to be researched and determined.

8. **How does this approach fit within advanced traffic management systems (ATMS)?**

ATMS are intended to respond to changes in traffic flow and integrate management of various functions including transportation information, demand management, freeway ramp metering and arterial signal control. In addition, ATMS implies collaborative action on the part of the involved transportation management agencies and jurisdictions. The proposed freeway management approach emphasizing mainline metering is consistent with the intended goals of ATMS. As such, evaluation of this freeway management system, possibly via a demonstration project, should qualify for federal funding under the IVHS program’s ATMS category.
Freeway Management System Operational Considerations

1. *When should the freeway management system be engaged?*

   The freeway management system should be engaged for as long as traffic volumes indicate there would otherwise be congestion on the freeway system. Algorithms can be developed for detectors located throughout the freeway system to determine when it is appropriate to engage and disengage the ramp and mainline meters.

2. *What metering rates should be utilized?*

   The determination of appropriate metering rates depend on the lane configuration at the individual metering point and the location of the mainline meter within the freeway management system. At some locations it may be appropriate to meter at 1,500 vphpl, while at others it may be necessary to meter at 1,700 or 1,800 vphpl. It may also be necessary to have additional lanes at these mainline metering points to ensure that throughput levels can be achieved. Typical on-ramp metering experiences indicate practical maximums of 900 to 1,200 vphpl.

3. *Should HOVs in an HOV queue bypass lane also be required to stop at the mainline meter?*

   The role of an HOV queue bypass is to give eligible vehicles a travel time advantage by allowing them to proceed ahead of the queue. An argument can be made that this advantage can be increased by providing a continuous green indication for HOVs. However, this approach may increase the violations of single occupant vehicles in the adjacent metered lanes. Another option could involve metering the HOV queue bypass at a less restrictive rate. This approach may preserve the concept’s integrity between the HOV and single occupant users while ensuring a high compliance rate and maintaining the benefits that mainline metering can provide.

4. *What are the enforcement needs for the metering operation?*

   Any mainline metering operation should be accompanied by the commitment of adequate enforcement to ensure compliance. Feedback from enforcement agencies and personnel is important in the mainline metering concept stage to ensure that the proposed configuration is enforceable. When a mainline metering project is first initiated, enforcement personnel should be frequently visible to motorists. Subsequently, appropriate compliance could be accomplished with periodic enforcement activities. Penalties should be set high enough to discourage repeat violations.

5. *Does mainline metering present any additional safety issues?*

   A predominant safety concern with mainline metering is the potential for rear-end collisions when traffic comes to a stop. This concern can be alleviated with adequate advance warning signs. For example, at a Southern California freeway mainline border
control point, advance warning signs are used to bring motorists travelling at high speeds to a complete stop. This has been accomplished without causing an increase in accident rates. Aside from this concern, mainline metering does not present any additional safety problems beyond typical ramp metering and mainline freeway operation. For this reason, an appropriate safety goal is to ensure that the accident rate in the vicinity of the mainline metering operation is similar to the accident rate for typical ramp and mainline freeway operation.

6. *Does mainline metering serve as an incident management tool?*

The primary goal of bridge/tunnel mainline metering is to provide increased downstream volumes and improved travel time approaching and through the bridge/tunnel facility. This means that non-recurring events should be addressed in an expeditious fashion, possibly prioritizing the management of these events over the upstream mainline demand in an attempt to mitigate motorist delays due to the incident. The mainline metering operation can serve as an important incident management component of the bridge/tunnel facility by controlling demand to allow for rapid response and removal of the incident.

7. *Should trucks be allowed to bypass the mainline meters?*

Given the amount of energy required to accelerate and decelerate heavy vehicles, it may be appropriate to allow trucks to bypass the mainline meters. Since this may bring complaints from other motorists, it is important to determine the savings associated with providing a truck bypass. Should all trucks be eligible to use the truck bypass or just certain types, i.e., three-axle, four-axle, or five-axle?

8. *Who or what agency should operate the freeway management system?*

The freeway management system should be operated and maintained by the agency that owns and operates the facility it is on. This is the approach utilized in areas currently employing ramp meters. Where sections of the same highway are owned and operated by different agencies, some form of cooperative agreement would be necessary to determine operating responsibilities and procedures.

9. *How should the mainline queues be managed?*

The queues forming at the mainline meters should be managed so that the time spent in the queue is approximately the same at each mainline meter location. This queue management approach will provide the most equitable distribution of delay and discourage motorists from exiting and re-entering the freeway to bypass mainline meters that are perceived to have longer queue delays.
10. How should it be determined where the freeway management system starts or when to add another mainline meter?

This can be determined based on the queue management approach employed. If it is determined that the time spent in a mainline queue should not exceed x minutes, or the length of a queue should not exceed x feet, then the freeway management system will need to be extended accordingly to maintain this desired level of operation.

**Freeway Management System Design Considerations**

1. *How should mainline metering be conveyed to motorists?*

   Mainline metering should be conveyed using conventional red and green indications similar to that utilized at existing bridges and tunnels. This provides the most direct means of control and is a familiar technique. Experience with both red-yellow-green and red-green signal indications on mainline and ramp metering projects indicate that the red-green approach is very successful and removes the indecision motorists sometimes exhibit during the yellow indication.

2. *Should the metering indications be simultaneous or staggered?*

   Simultaneous red-green indications and lane-staggered red-green indications have both been used with equal success with a two-lane approach. A staggered red-green indication approach is preferred when there are three or more lanes provided at the metering point because this will facilitate the downstream merge into the reduced capacity section. The need to allow one car per green versus two cars per green is again dependent on upstream and downstream conditions. Both approaches are workable provided they allow enough volume to sufficiently utilize the downstream capacity.

3. *What design criteria should be used for transitions, stopping sight distance, lane widths, etc.?*

   The type of design criteria to use for incorporating transitions, merges, stopping sight distances and other geometric features into the metering operation should be similar to existing criteria used to design typical highway facilities. For this reason, the geometric configuration in the vicinity of the mainline metering operation can be developed in accordance with the American Association of State Highway and Transportation Officials (AASHTO) design manual or the local state DOT design manual.

4. *Where should advance warning signs be placed?*

   Advance warning signs should be located sufficiently upstream of the mainline metering point to allow enough distance for vehicles to come to a complete stop before reaching the queue from the meter. For a vehicle travelling at 65 mph this would necessitate the first advance warning sign being placed approximately two miles upstream followed by additional signs displaying messages preparing motorists to stop. It is
desirable to install changeable message signs in this area to provide motorists with real-time information regarding downstream traffic conditions (i.e., accident on bridge or within tunnel, maintenance activities, etc.).

5. **What kind of enforcement areas are required?**

Mainline metering serves to facilitate the enforcement process. Enforcement areas can be located immediately downstream of the metering point in an area visible to all motorists. The presence of an enforcement officer serves as an effective means of deterring violations. If a violation does occur, the enforcement vehicle needs to accelerate and apprehend the violator at a dedicated location. This usually requires a downstream area either on/within or on the other side of the bridge/tunnel section that is reserved for this purpose. This type of visible enforcement strategy, combined with appropriate penalties to discourage repeat violators and first offenders, is usually sufficient to ensure a high compliance rate.

6. **What is the appropriate sequence of implementation?**

Implementation of the freeway management system should begin within the urban area and proceed to outlying areas. Other ramp and mainline meters can be added to extend the freeway management system as traffic volumes warrant.

Just as arterial streets use traffic signals to stop vehicle progression and allow cross-street traffic to proceed, optimal freeway management may require mainline meters in certain situations. Motorists may tolerate the slowdown at the meter if they attain free-flow travel conditions downstream. In addition, mainline meters can serve as an appropriate incident management tool. The concept of stopping vehicles via mainline meters during periods of peak demand may be palatable in areas where vehicles are already in congested conditions during the peak period.

### 4.2 Isolated Applications of Mainline Management

In addition to employing mainline metering as part of an overall freeway management system, situations exist where an isolated application of mainline metering can better manage traffic operations. These isolated applications can include tunnels, bridges and typical bottlenecks. Planning, operational and design considerations for these mainline metering applications are discussed below.

**Tunnel/Bridge Management**

Due to limited available roadway capacity at bridges and tunnels, it may be necessary to regulate vehicle ingress during periods of peak demand. Experience at the San Francisco-Oakland Bay Bridge, Hampton Roads Bridge-Tunnel and Baltimore Harbor
Planning Considerations

1. Will mainline metering improve traffic flow on bridges and within tunnels?

Bridge/tunnel experience indicates that mainline metering can increase throughput and speeds by approximately 10 to 15 percent. These benefits must be perceived by motorists using the bridge/tunnel to ensure viability of the metering operation. Mainline metering should not be engaged when throughput and speed increases are not perceived by motorists because the absence of these benefits may lead to complaints and public outcry to remove the metering control.

2. When is it appropriate to use mainline metering at bridges and tunnels?

Mainline metering should be used at bridges and tunnels whenever there is enough congestion upstream of the bridge or tunnel to create a significantly long traffic queue and a reduction in downstream vehicle throughput. The definition of what is “enough congestion” and what is a “significantly long queue” will vary from location to location. As a general rule, candidate locations for mainline metering can be considered whenever vehicular throughput is less than 1,800 vphpl.

3. Should mainline metering be considered even if there is not a capacity reduction on the bridge or within the tunnel?

Existing traffic flow experiences on bridges and within tunnels dictate separate answers to this question. The Bay Bridge is an example of a capacity reduction because there are three upstream freeways leading to the bridge. However, there are many bridges where the upstream roadway capacity is identical to the bridge section and, for the most part, there are not any operational deficiencies. Consequently, unless congestion, queue and volume considerations are satisfied, there does not appear to be a need to meter traffic entering bridges unless there is a capacity reduction.

Traffic operation within tunnels is somewhat different. Limited field experience at both the Baltimore Harbor Tunnel and the Hampton Roads Bridge-Tunnel has shown that metering the upstream lanes prior to the tunnel portal will improve traffic flow in the tunnel, even if the same number of lanes are provided upstream and downstream. It appears that the closed-in nature of tunnels functions as a capacity reduction even though the number of lanes does not change. Given this phenomenon, it appears that a portal control capability may be appropriate for many tunnels even if its primary use is to remove the potential for vehicle queues within the tunnel. When considering the...
need to maintain air quality within the tunnel and maintain incident management capability, some form of tunnel mainline or portal control may be appropriate.

**Operational Considerations**

1. *For how long should the metering operation be engaged?*

   The metering operation should be engaged for as long as congestion and traffic queues form upstream of the bridge/tunnel entrance. Algorithms can be developed for detectors located both upstream and downstream of the metering point to determine the appropriate time to engage and disengage the mainline metering operation. Whenever traffic volumes are low enough not to cause congestion, the mainline meters can be turned off or left on continuous green.

2. *What metering rates should be utilized?*

   Metering rates can be reduced to two seconds per green; however, this may lead to enforcement problems because it is difficult for motorists to come to a stop at this rate. The determination of appropriate metering rates depend on the lane configuration both upstream and downstream of the metering point. Obviously, metering rates should be set to maximize the downstream capacity of the tunnel/bridge. It is desirable to have more lanes at the metering point than on the bridge or within the tunnel to ensure that the available downstream capacity is fully utilized. Metering a travel lane can reduce the theoretical capacity of that lane. For example, typical on-ramp metering experiences indicate practical maximums of 900 vphpl. Allowing two cars per green can increase this value to approximately 1,200 vphpl. If the capacity of the bridge/tunnel is 1,600 vphpl, there will be 400 vphpl of non-utilized capacity.

**Design Considerations**

1. *How should the mainline metering operation be conveyed to motorists?*

   Mainline metering at existing bridge-tunnel facilities should be accomplished with conventional red and green signal indications. Bridges employing mainline metering usually have signal indications mounted on an overhead structure, with one signal mounted directly over each lane.

   Tunnel facilities employing mainline metering can have the signal indications mounted on an overhead structure, while other locations mount the signals on poles located adjacent to the lanes feeding into the tunnel. The latter approach is employed because many tunnels are two lanes wide in each direction and a signal indication can be mounted on a pole adjacent to each lane. This approach works sufficiently well, although, for mainline metering purposes, it is recommended that signal indications be mounted on an overhead structure. In addition, the metering point should be located upstream of the tunnel portal. The signal indications should not be mounted on the tunnel structure. This approach is not recommended for two reasons. First, if there are
more lanes upstream of the tunnel portal than within the tunnel itself, sufficient distance is needed to allow vehicles to merge into their lanes prior to the tunnel portal. Second, even if there is not a capacity reduction approaching the tunnel, there needs to be sufficient distance to stop traffic and allow emergency vehicles to enter the tunnel during incident management activities. The above guidelines for locating the tunnel metering point are also applicable for mainline metering at bridges.

2. *How should mainline metering facilities be oriented with respect to toll plazas?*

Many bridges and tunnels have toll plazas located upstream of the bridge/tunnel entrance. The metering operation should not be incorporated at the toll plaza because the time required for toll collection will reduce the downstream throughput. Although AVI techniques will reduce the time necessary for toll collection, they will not be able to control the amount of traffic entering the bridge/tunnel. Thus the metering control should be separate and located downstream of the toll plaza (Figure 11).

3. *Where should HOV queue bypass lanes be provided?*

The Bay Bridge, which has 17 toll booths prior to the mainline meter, provides dedicated lanes for HOVs to travel through the toll plaza (HOVs do not have to pay a toll) enabling them to proceed to the metering bridge without any delays. These HOV toll booths are located on each end of the toll plaza. Single occupant drivers must use the toll booths between the ones designated for HOVs only. The California DOT has found this configuration to be very successful. Previously, the HOV-designated toll booths were located in the middle of the toll plaza resulting in operational problems upstream of the toll plaza. For this reason, in situations where there are a significant number of lanes approaching the mainline meter, it is recommended that HOV queue bypasses be located at the far left or far right (preferably in proximity to the majority of originating users to discourage weaving).

For tunnel sections and bridges where there are not as many lanes at the metering point, it is desirable to reserve an outside lane for HOV vehicles. The decision to provide HOV queue bypass on the left side or the right side should be dependent upon local preference.

**Management of a Typical Bottleneck**

A “typical bottleneck” for this discussion is a physical reduction in downstream capacity. Examples of typical bottlenecks include lane drops occurring along the freeway mainline or a reduction in downstream travel lanes often occurring when two freeways merge together. In certain situations, traffic operation through these typical bottlenecks may benefit by using mainline metering to regulate the number of vehicles entering the bottleneck area.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

Figure 11: Toll Plaza and Metering Point Design Concept
The following discussion identifies when mainline metering should be considered to better manage traffic operation through typical bottlenecks. Similar to the tunnel/bridge management section above, questions address major planning, operational and design issues. Because there are many similarities to mainline metering guidelines for tunnel/bridge management and typical bottleneck management, only those planning, operational and design issues that are different from those previously discussed are noted below.

**Additional Planning, Operational and Design Considerations**

1. What degree of capacity reduction through a typical bottleneck is needed to consider a mainline meter?

   The amount of capacity reduction needed to consider a mainline meter depends on each situation; however, the primary requirement is severe congestion. Capacity reductions along a typical freeway are shown in Figure 12. Historically, there has not been any form of control to regulate traffic through these types of bottlenecks; vehicles tend to fend for themselves when maneuvering through the constrained section. Based on this experience, it appears that mainline traffic operation associated with a capacity reduction of one lane (a lane drop) flows reasonably well. Even during periods of peak travel demand, motorists are able to negotiate the lane drop without too much delay. Resulting traffic queues upstream of the lane drop are generally within levels tolerable to the driving public.

   When the mainline capacity reduction is more than a typical lane drop (i.e., drops of two lanes or more with all upstream lanes operating at capacity), the resulting traffic queues and delays could benefit by traffic management control. As a general rule of thumb, when the freeway mainline experiences a capacity reduction of 40 percent or more, mainline metering should be considered to better manage traffic during periods of peak demand. Configurations where the capacity reduction is more than a lane drop but less than 40 percent must be evaluated on a case-by-case basis. For these situations, mainline metering may or may not be an appropriate management strategy.

   Another situation where the above rule of thumb can be superseded is at the intersection of two freeways that form a “T” or “Y” configuration as shown in Figure 13. Often, freeway interchanges with these configurations experience a reduction in capacity either upstream or downstream of the merge point. The combination of the reduction in capacity and the merging traffic from another freeway facility can result in significant delays during periods of peak demand. This is true even if the capacity reduction is a typical lane drop. Mainline metering can be used to regulate the amount of traffic entering the “funnel” section of the “Y” or “T” interchange to improve overall traffic operations. This situation is analogous to the San Diego SR 67/I-8 metering operation discussed earlier.
Figure 12: Typical Examples of Reductions in Mainline Freeway Capacity
Figure 13: Examples of Capacity Reduction at "T" or "Y" Freeway Interchange
2. Given an existing bottleneck condition, how much congestion is necessary to implement a mainline metering operation?

The degree of congestion necessary to consider mainline metering for a typical bottleneck is dependent upon what the local community is willing to tolerate. In many situations the bottleneck condition may be of a short enough duration that it would not be appropriate to consider mainline metering. The mainline metering traffic management approach is not something to consider unless there is a significant congestion problem resulting in lengthy vehicular queues and delays. In addition, it is important that a public participation process be conducted to determine whether the public will support a traffic management strategy for the bottleneck area (Chapter 5).

3. At “Y” and “T” interchanges, should both freeways be metered entering the funnel section?

Both freeway legs entering the funnel section do not have to be metered. The decision to meter one or both freeway legs is dependent on travel demand, geometrics and the local area operational plan. For example, if the demand of both freeways is approximately the same, and the intent is to minimize delays on each facility, then it would be appropriate to meter both legs. However, if the operation of one freeway is more important than the other, it may be more appropriate to meter just one leg (as is the case in San Diego).

Isolated applications of mainline management are not a new or untried management approach. The Bay Bridge, Baltimore Harbor Tunnel, and Hampton Roads Bridge-Tunnel are documented examples of how mainline metering can be used to improve traffic operations. These experiences, together with the planning, operational and design considerations presented throughout this chapter, can be applied to other isolated bottleneck locations in an effort to improve mainline operations.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
5.0 IMPLEMENTATION ISSUES OF MAINLINE METERING, CONGESTION/PEAK PERIOD PRICING AND SMART CORRIDORS
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
5.0 IMPLEMENTATION ISSUES OF MAINLINE METERING, CONGESTION/PEAK PERIOD PRICING AND SMART CORRIDORS

The previous chapters addressed technical issues associated with FMS. Chapter 2 briefly noted FMS advantages and disadvantages; Chapter 3 presented a more detailed analysis of the potential benefits of mainline metering; and Chapter 4 outlined a freeway management system designed to make the most efficient use of a freeway facility and identified the planning, operational and design issues needing further investigation. The purpose of this chapter is to qualitatively assess the institutional issues that affect implementation of FMS. Three FMS were selected for this evaluation: mainline metering, congestion/peak period pricing, and SMART corridors. These strategies were selected because they offer the most potential for improved management of freeway congestion and, conversely, may be the most difficult to implement.

A survey was employed to determine the issues that needed to be addressed to facilitate implementation of the above FMS. This survey was mailed to individuals across the country who would likely be responsible for implementing these transportation strategies in their respective area. Responses represented a multitude of agencies including metropolitan planning organizations, federal and state departments of transportation, cities, toll road authorities, and others. The distributed survey is presented in Appendix C together with tabulated participant responses. The following discussion summarizes the survey results and offers some plausible interpretations.

5.1 Survey Findings

To facilitate interpretation of the survey results presented in Appendix C, each question is discussed below. The following pages present the topic of each question, the goal it set out to achieve, and the general response of the survey participants.

Question 1: Strategy Preference

Goal: To determine how supportive the potential implementors were of each strategy under consideration.

Response: The survey participants were strongly supportive of SMART corridors. Mainline metering also received a generally favorable response. Congestion pricing did not receive as much support, with most survey participants indicating either a neutral or somewhat favorable response.
**Question 2: Implementation Factors**

**Goal:** The ability to implement a project is often dependent upon a variety of factors concerning leadership, funding, understanding and previous experience with the concept. This question attempted to identify the importance of these factors within each strategy.

**Response:** Leadership was viewed as critically important for all three strategies. The survey indicated that leadership was necessary from all levels of local government including state DOTs, regional transportation agencies, and local public officials. Federal leadership was viewed as supportive to the implementation process, though not a necessity.

It was felt that limited funding would have a minimal impact on the ability to implement mainline metering and congestion pricing strategies. Funding availability was viewed to have a more significant effect on the viability of SMART corridors, probably due to the intensive capital investment needed to implement a corridorwide system.

Both general public and political official understanding and acceptance of mainline metering and congestion pricing was viewed as essential to the implementation process. The need for public understanding and prior acceptance was not as great of a concern for SMART corridors. This response was expected because implementation of SMART corridors is more of a passive strategy than either mainline metering or congestion pricing, which directly impact motorists.

Finally, the need for previous experience with these strategies was viewed as nice to have, but not a requirement for implementation. It appears that an appropriate well-designed public participation program can overcome a lack of local area experience with these strategies.

**Question 3: Need for a Champion**

**Goal:** To determine if a single champion/pioneer is necessary to promote implementation of these strategies and, if so, who the champion should be.

**Response:** The survey indicated that a champion is necessary for each strategy. The responses appeared to indicate that a state DOT representative would be the most appropriate champion for mainline metering or SMART corridors. A local politician such as the mayor as an alternative champion was seen as somewhat effective. Considering that most candidate highway facilities for mainline metering and SMART corridors will be operated by the state DOT, the combined leadership of a state representative and local politician would make an effective implementation team.

The survey respondents did not indicate that a state DOT champion would be as appropriate for congestion pricing. The responses placed a greater importance on local political leadership (county supervisors, mayors). Given that congestion pricing directly impacts motorists, it appears that a local champion would be a more appropriate leader
for advocating the need to have area motorists pay to better manage local congestion and serve as a revenue source for other highway improvements.

**Question 4: Involvement in Planning/Education Process**

**Goal:** The planning, project development and implementation of any new strategy is usually best handled through a steering committee of local and regional entities. The steering committee can serve as a decision making, constituency building and educating body of the participants involved. The goal of this question was to determine who these participants should be within each strategy.

**Response:** The respondents indicated that steering committee participants should include all potentially affected parties and that these participants were necessary for all strategies. A steering committee was recommended to include the following representatives: regional transportation agency; transit agency; state DOT; local political representatives (i.e., mayors, supervisors); local federal representative; interest groups (e.g., trucking, automobile club, neighborhood organizations); and, at certain times, media representatives.

**Question 5: Legislative Mandate or Policy**

**Goal:** The purpose of this question was to determine if some form of legislative mandate or policy direction would be necessary or helpful in deciding to pursue these types of strategies and, if so, where this mandate should come from.

**Response:** Virtually all respondents indicated that a legislative mandate was necessary for congestion pricing, and a majority of the respondents indicated that a mandate would be helpful for mainline metering and SMART corridors.

It was apparent from the survey results that a congestion pricing mandate/policy direction should occur at the local, not federal, level. The most frequently noted suggestions regarding who should initiate this mandate included the governor, mayor, regional transportation agency, and state legislature.

Similar to the responses for question three, the survey participants indicated that the state DOT was the most appropriate agency to initiate policy direction for mainline metering or SMART corridors.

**Question 6: Educating Decision Makers**

**Goal:** This question attempted to identify the most appropriate way to convince or educate decision makers that mainline metering, congestion pricing and SMART corridors can better manage traffic congestion.

**Response:** A local demonstration project was rated as the most effective means of educating decision makers of the benefits associated with all strategies.
from traffic experts, previous experience in other areas, and corridor planning studies were viewed as being somewhat effective.

**Question 7: Educating the General Public**

**Goal:** This question attempted to identify the most appropriate way to convince or educate the general public that mainline metering, congestion pricing and SMART corridors can better manage traffic congestion.

**Response:** The response to this question was virtually identical to question six. A local demonstration project was viewed as the most effective means of educating the general public of the benefits associated with all strategies. Statements from traffic experts and previous experience in other areas were viewed as being somewhat effective.

**Question 8: Communicating Strategies to the Public**

**Goal:** The viability of any new or innovative transportation solution hinges on public acceptance. Prior to implementation of any strategy it is essential that the public be informed and exposed to the reasons these approaches are being pursued. This question attempted to identify the best means of communicating these strategies to the general public.

**Response:** Most of the respondents indicated that the media (i.e., newspapers, radio and television discussions) was the most effective means of communicating these strategies. Public meetings, educational forums, brochures and targeted public marketing were all viewed as being somewhat effective. The intent of this process is to gain public acceptance by presenting a logical case documenting the need for this new approach. If this information is provided in a well organized public education and marketing campaign, it is much more likely that the public can reach a well informed decision. Whether the public is agreeable or not to the proposed concept, the above approach should be executed. Projects that are quickly implemented without this participation process can easily fail (whether the strategy is successful or not) due to the public outcry that can occur from lack of information.

**Question 9: Necessary Conditions**

**Goal:** This question focused on determining what conditions were necessary to justify consideration of each of these strategies.

**Response:** The survey participants indicated that significant ongoing congestion must exist to consider implementation of mainline metering and congestion pricing. It was felt that ongoing congestion should exist to consider implementation of a SMART corridor, although it was not viewed as a requirement.

The responses also indicated that a legislative/political level policy mandate and lack of success with traditional solutions must exist to consider implementation of congestion
pricing. It appears that the respondents believed that motorists would have to be very frustrated and desperate for a new approach before they would give serious consideration to congestion pricing.

Legislative policy mandates were considered unnecessary for implementation of mainline metering or SMART corridors. However, it was felt that both funding and lack of success with traditional solutions should exist before consideration of the above two strategies.

**Question 10: Demonstration Project**

*Goal:* To determine if the survey participants would be willing to consider a demonstration project in their area to evaluate the advantages/disadvantages of any of the three strategies.

*Response:* Approximately 84 and 93 percent of the survey participants indicated they would be willing to consider a demonstration project for mainline metering and SMART corridors, respectively. Only 44 percent were willing to consider a congestion pricing demonstration project.

It is obvious that there are significant implementation and marketing issues that must be dealt with when considering these strategies. The following section uses the survey results to develop a hypothetical implementation/marketing plan.

### 5.2 Hypothetical Implementation/Marketing Scenario

It is obvious that there are several implementation and marketing issues that must be dealt with to successfully implement these FMS. This section identifies a potential implementation/marketing scenario that could be used during the project development process to implement one of these strategies. As a supplement to the planning, operational and design considerations presented in Chapter 4, and to facilitate this discussion, the hypothetical implementation/marketing scenario will be focused on mainline metering.

The decision to consider mainline metering as a traffic management tool at a specific location can originate from any agency or individual; however, the local operating agency should ultimately be responsible for pursuing its implementation. Since mainline metering would most likely be used to improve traffic operations approaching bridges and tunnels or on highways/freeways, local bridge/tunnel authorities and state DOTs would be the most appropriate leaders in pursuing implementation. Without a commitment by these operating agencies to at least consider mainline metering for their facilities, the likelihood of gaining outside support to pursue implementation becomes extremely remote.
The first step in the marketing/implementation process is the formation of a steering committee early in the project development process, preferably at the beginning of the planning stage. This committee would consist of all potentially affected parties, as discussed in Question 4 above. Forming a steering committee early on allows members to express concerns up front, have a voice in the decision-making process, and learn the pros and cons associated with mainline metering. Ideally, all steering committee participants will ultimately become promoters of the concept as they learn of the benefits to be achieved.

The first assignment for the steering committee would be to determine the benefits of the mainline metering operation for the area under consideration. A range of expectations should be the product of this effort, similar to those outlined in Chapter 4, based on previous experience and appropriate analysis. If the committee determines that these expectations are worth continued investment in mainline metering, the planning and project development process can continue.

Once it is decided to pursue implementation of the mainline metering concept, it is critical to determine how it should be marketed. Appropriate marketing is an essential element of any non-traditional transportation solution. Improper marketing can doom a project, no matter how beneficial the proposed concept might have been. Once the public formulates a negative perception, it becomes virtually impossible to overcome.

The steering committee can collectively determine the most appropriate form of marketing to pursue. Types of marketing to consider include:

- Community relations
- Constituency building
- Paid advertising
- Direct mail
- Public information materials (sources other than direct mail)
- Media relations
- Public outreach (e.g., speakers bureau, helpline)
- Employment-site marketing

Whichever technique is utilized, marketing can educate individuals as to the intended purpose, benefits, and rationale for pursuing mainline metering. When done properly, the public will be educated and well informed and able to draw their own conclusions based on the materials presented.
5.3 Summary of Implementation Issues

The overall purpose of this survey was to gain an understanding of the likelihood of implementing mainline metering, congestion pricing or SMART corridors from the individuals who would most likely be responsible for pursuing these strategies in their respective areas. From an overall perspective, the survey participants indicated that SMART corridors and mainline metering would stand more of a chance of being implemented than congestion pricing. As a result of this perception, the participants believed that a legislative mandate was necessary to pursue congestion pricing implementation, but not necessary for SMART corridors or mainline metering.

The respondents indicated that a champion was necessary to promote all strategies, and that a steering committee of affected parties should be formed to address the technical and institutional issues that surface during the project development process. In addition, results generally indicated that local area government agencies should take the lead in pursuing implementation of these strategies. SMART corridors and mainline metering should be promoted by the state DOT, while an alliance comprising most area transportation agencies should promote congestion pricing.

Respondents also indicated that significant ongoing congestion was a prerequisite to considering implementation of any strategy. Traditional approaches for dealing with local area congestion should be exhausted, and local area motorists should feel frustrated with the congestion situation and willing to try something different in an attempt to alleviate it.

Finally, public and political involvement was seen as the most critical component affecting implementation of these strategies. Public outreach programs were seen as vital to a better understanding of these strategies and the benefits expected to occur. Reaching target audiences in marketing or public awareness programs is necessary when developing a public and political constituency. This program should be continuous from concept development to implementation to maintain a constant awareness of project benefits.

Successful implementation requires careful planning and preparation with a sensitivity to the local environment. These strategies should not be forced or steamrolled through the implementation process, but rather cultivated within a local area to address a persistent congestion problem.
Questionnaire on Freeway Management Strategies (FMS)
Members of the Fellowship Review Group

February 1992

The answer sheet for the following questions is provided on page A-5.

1. From the list of FMS shown on the following pages, which strategies are currently being used in your area? (Check as many as appropriate)

2. Please check the FMS you feel require more documentation concerning guidelines needed to aid in the planning, design and operation of such strategies.

3. On a scale of 1 to 10, rank the relative benefit you feel each FMS will have on improving mainline traffic flow in the future. (1 = very beneficial, 10 = not beneficial)

Please answer the above question strictly from a traffic flow benefit standpoint. Implementation likelihood/concerns are addressed in the following question.

4. On a scale of 1 to 10, please rank each FMS in terms of its implementation potential. (1 = easy implementation, 10 = very difficult to implement)

5. If the implementation issue is solvable, and appropriate planning, operational and design guidelines can be developed, which strategies would you use in your area?

6. Please rank the three FMS you feel can offer the most potential towards better managing mainline traffic flow. (1 = most preferred, 2 = second most preferred, 3 = third most preferred)

7. Please check what you feel are the advantages and disadvantages associated with each FMS shown on pages A-2 through A-4. If you think of any other advantages or disadvantages please write them in.
FMS Advantages and Disadvantages

Please check what you feel are the advantages and disadvantages associated with each FMS. If you think of any other advantages or disadvantages please write them in.

Variable Speed Control

**ADVANTAGES**
- Maintains optimal speed
- Improves vehicle throughput
- Good LOS in express facility
- Benefits through trips

**DISADVANTAGES**
- Potential rear-end collisions
- Enforceability problem
- No change to non-express lanes
- No benefit to short trips

Limited Access Express Lanes

**ADVANTAGES**
- Regulates vehicular entry
- Improves on-ramp merge
- Improves mainline operation

**DISADVANTAGES**
- Does not regulate mainline or freeway connectors
- Potential ramp queue back-up to city street

Ramp Metering

**ADVANTAGES**
- Regulates high volume connectors
- Improves mainline operation
- Improves connector merge

**DISADVANTAGES**
- Resulting queue can extend to upstream connectors freeway mainline
- Does not regulate mainline
- Potential for multiple metering of single trip

Interchange Connector Metering
### Mainline Metering

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulates mainline traffic</td>
<td>Queue forms upstream of metering point</td>
</tr>
<tr>
<td>Combined with ramp metering can improve flows within the control section</td>
<td>Potential for rear-end accidents</td>
</tr>
<tr>
<td>Ridesharing incentive when used in conjunction with an HOV bypass lane</td>
<td>Political/public hurdles</td>
</tr>
<tr>
<td>Avoids queue back-up at on-ramps downstream of mainline meter</td>
<td></td>
</tr>
</tbody>
</table>

### Geometric Designs that Function as a Metering Point

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminates the perception that a traffic signal or meter is causing congestion</td>
<td>Perceived as a bottleneck or congestion point that needs attention</td>
</tr>
</tbody>
</table>

### Congestion/Peak Period Pricing

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users pay for the congestion they create</td>
<td>Political/public hurdles</td>
</tr>
<tr>
<td>Ridesharing and transit incentive</td>
<td>Price of congestion may be inelastic in certain areas</td>
</tr>
<tr>
<td>Encourages individuals to make marginal utility trips during less congested times</td>
<td>Outcry of being charged twice (i.e., gas tax and toll)</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
**Driver Information Systems**

**ADVANTAGES**
- Motorists can get real-time information on traffic conditions
- Motorists can decide which route to use
- 
- 

**DISADVANTAGES**
- No direct control of mainline operation
- 
- 

**Overhead Lane Control Signals**

**ADVANTAGES**
- Directs motorists to appropriate lanes as a means of improving traffic operation
- Good for managing traffic around incidents
- 
- 

**DISADVANTAGES**
- Limited benefit for recurring traffic congestion
- Enforcement concern
- 
- 

**HOV Lanes**

**ADVANTAGES**
- Maintains mobility in congested corridors
- Provides incentive to rideshare
- 
- 

**DISADVANTAGES**
- No benefits to general-purpose lanes
- 
- 

**SMART Corridors**

**ADVANTAGES**
- Using driver information systems can direct vehicles onto less congested routes
- 
- 

**DISADVANTAGES**
- Implementation costs can be expensive
- Not applicable everywhere, need appropriate parallel facilities
- 
- 

Thank you for your assistance in completing this questionnaire.

Other comments:
- 
- 
- 
- 

---

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
### Answer Sheet for Questions 1 through 6

#### Strategies

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Speed Control</td>
<td>q</td>
</tr>
<tr>
<td>Limited Access Express Lanes</td>
<td>q</td>
</tr>
<tr>
<td>Local Street Ramp Metering</td>
<td>q</td>
</tr>
<tr>
<td>Interchange Connector Metering</td>
<td>q</td>
</tr>
<tr>
<td>Mainline Metering</td>
<td>q</td>
</tr>
<tr>
<td>Geometric Designs that constrain/meter traffic at preselected points</td>
<td>q</td>
</tr>
<tr>
<td>Congestion/Peak Period Pricing</td>
<td>q</td>
</tr>
<tr>
<td>Driver Information Systems</td>
<td>q</td>
</tr>
<tr>
<td>i.e., changeable message signs, cellular phones, radio reports</td>
<td>q</td>
</tr>
<tr>
<td>Overhead Lane Control Signals</td>
<td>q</td>
</tr>
<tr>
<td>HOV Lanes</td>
<td>q</td>
</tr>
<tr>
<td>SMART Corridors—Parallel facilities integrated with the mainline corridor</td>
<td>q</td>
</tr>
</tbody>
</table>

*Other FMS (write-in)*

<table>
<thead>
<tr>
<th></th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>q</td>
</tr>
<tr>
<td></td>
<td>q</td>
</tr>
</tbody>
</table>

*Any other FMS which would be appropriate to implement in the near term and are compatible with future IVHS technologies?*
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

APPENDIX B
MAINLINE METERING SIMULATION RESULTS
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
This appendix presents the results of a computer simulation conducted to determine if mainline metering can provide additional freeway operational benefits beyond those achieved from ramp metering. Documentation of the INTRAS simulation model, the study area network, simulation methodology and results is presented below.

**B.1 The INTRAS Computer Simulation Model**

INTRAS was written in 1977 by KLD Associates for the FHWA. It was selected as the analysis tool for this study because its car-following algorithms provide for a realistic simulation of traffic operations on an actual freeway. INTRAS is a microscopic, as opposed to macroscopic, simulation model. Microscopic models simulate the movement of individual vehicles, while macroscopic models simulate the flow of a group of vehicles. A microscopic model provides a more detailed study than a macroscopic model, together with the potential for more accurate results. On freeways with traffic demand below capacity, traffic flow is smooth and can be modeled reasonably well with the general parameters of a macroscopic model. However, in congested flow, traffic behavior becomes more complex. Because this research focuses on freeway conditions under congested flow, it is important that the vehicular behavior be modeled as accurately as possible. For these reasons, the INTRAS microscopic model was selected.

Freeway traffic flow is dominated by the characteristics of vehicular action and interaction. To accurately simulate freeway traffic, a wide range of parameters and algorithms was incorporated and calibrated into the INTRAS model. A total of five different vehicle types are incorporated into the model and can be specified by the user. These types are low performance passenger car, high performance passenger car, intercity bus, single unit trucks and trailer trucks. Each type of vehicle has a specific acceleration and deceleration behavior that is incorporated into the simulation.

The distribution of freeway volumes among lanes and the differences in mean vehicular speeds between lanes were also incorporated within INTRAS. These parameters were determined statistically from data collected on the Long Island Expressway in New York and the San Diego and Santa Monica Freeways in Los Angeles. In addition, the INTRAS simulation program incorporates detailed car-following and lane-changing behavior algorithms. For specific details on all of the above parameters, consult the INTRAS reference manuals cited in the bibliography.
B.2 The Study Area Network

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

For simulation purposes the freeway was divided into eight segments of 2,000 feet each. Free-flow speed on the mainline was assumed to be 65 mph, while free-flow speed for the on-ramp was assumed to be 55 mph. The one lane on-ramp also contained a 500-foot auxiliary lane to facilitate vehicles merging from the on-ramp onto the freeway mainline. The simple freeway network is illustrated in Figure B-1. Although this freeway network is somewhat idealized, it is felt that the qualitative and quantitative results obtained from the simulation are analogous to a typical non-bottleneck freeway condition.

B.3 Simulation Methodology

The mainline metering evaluation was based on a variety of mainline volume and on-ramp control conditions. Previous experience has shown that the freeway mainline operates very well when mainline volumes are lower than 1,800 vphpl. For this reason, simulations were conducted with mainline service volume rates of 1,800 vphpl and higher. Specific mainline service volume rates analyzed included 1,800, 1,850, 1,900, and 1,950 vphpl. The vehicular demand on the on-ramp was kept constant at 1,200 vph. However, the rate at which this on-ramp demand could access the freeway was simulated for the following conditions: no control; ramp metering at three seconds; ramp metering at four seconds; and ramp metering at five seconds. Ramp metering rates greater than five seconds were not simulated. Obviously, the more restrictive the metering rate, the better the freeway operates, since fewer cars ingress the facility. As the metering rate becomes more restrictive, the length of the on-ramp queue increases and can extend back to the arterial street, drawing objections from local jurisdictions.

For each mainline service volume condition, simulations were first performed for a base case assuming no form of control on either the on-ramp or mainline. Simulations were then performed using on-ramp metering rates of three, four and five seconds. Mainline metering was then simulated and evaluated for each of the three ramp metering conditions. In general, the mainline was metered at approximately 50 to 150 vphpl less than the service vol-
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.

Figure B-1: Freeway Study Area Network
ume demand. For example, if the service volume demand was 1,950 vphpl, mainline metering was instituted to feed the downstream freeway at a rate of 1,900 or 1,800 vphpl. Freeway conditions were simulated for a 30-minute time period. Several measures of effectiveness were used to compare the results of these simulations including downstream vehicle throughput, overall speed and overall travel time in vehicle-minutes.

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

B.4 Results

Vehicular Throughput

Figures B-2 through B-5 depict histograms of downstream vehicle throughput (at the end of the study area network) for the various combinations of mainline service volumes and on-ramp and mainline metering rates. It is important to realize that the combination of the mainline and on-ramp demands result in a total hourly demand of 6,600 to 7,050 vehicles downstream of the study area network. In addition, because traffic operations were simulated for a 30-minute time period, the maximum downstream vehicular demand would range from 3,300 to 3,525 vehicles.

Figure B-2 indicates that, for a mainline service volume of 1,800 vphpl, the downstream vehicular throughput remains relatively unchanged for each of the control strategies simulated. The implementation of metering at the on-ramp does not increase the downstream mainline throughput compared to the no-control scenario. The reason for this result is that even without ramp metering, there are sufficient gaps in the mainline traffic stream for entering vehicles to merge onto the freeway without causing a reduction in downstream vehicular throughput. In fact, with a three-second ramp metering rate, the vehicle throughput went down slightly. A three-second ramp metering rate equates to an on-ramp volume of 1,200 vpl, which is the demand on the ramp. The ramp meter slows down these vehicles compared to the no-control scenario, causing the slight downstream throughput reduction.

Downstream vehicle throughput was also determined using both ramp metering and mainline metering at a rate of 1,750 vphpl. The results indicate that the downstream traffic
Figure B-2: Mainline Service Volume = 1800 VPHPL
Downstream Volume in Link 8
volume is slightly lower compared to the ramp metering alone scenarios. This result was expected given that the network was able to effectively handle the ramp and mainline demands under the no-control scenario. With a service volume of 1,800 vphpl, mainline metering would only serve to slow down vehicles, causing a reduction in downstream throughput.

The downstream throughput volumes for a mainline service volume of 1,850 vphpl are shown in Figure B-3. In general, these results are similar to those mentioned above with two exceptions. The five-second ramp metering alone scenario and the combined scenario of four-second ramp metering with mainline metering at 1,800 vphpl resulted in an increase (about 2.5 percent) in downstream throughput compared to the no-control option.

Figures B-4 and B-5 present the downstream traffic volume results for mainline service volumes of 1,900 and 1,950 vpl, respectively. These figures illustrate that ramp metering alone appears to increase the downstream traffic volume approximately three to four percent compared to the no-control scenario. It appears that uncontrolled on-ramp traffic causes a slight reduction in the downstream traffic volume due to the increase in mainline demand. Appropriately regulating on-ramp demand appears to eliminate the platooning of entering vehicles that can cause the reduction in downstream mainline volumes. When mainline metering is combined with on-ramp metering, the downstream traffic volume appears to increase an additional three percent compared to the ramp metering only scenarios. The above result holds true for mainline service volumes at both 1,900 and 1,950 vphpl.

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

**Average Travel Speed**

The average speed for each traffic control scenario and mainline service volume are shown in Figures B-6 through B-9. In each figure, average travel speed downstream of the mainline meter and average travel speed for the entire network are shown for each control strategy. For the no-control and ramp metering alone scenarios, the average travel speed downstream of the mainline meter is shown for comparison purposes and reflects the average freeway speed downstream of where the mainline meter would have been. The average travel speed for the entire network takes into consideration the vehicles entering from the on-ramp as well as those upstream of the mainline meter.

For a mainline service volume of 1,800 vphpl, Figure B-6 indicates that the average network travel speed increases slightly as the ramp metering rate becomes more restrictive. In addition, the average freeway speed downstream of the mainline meter also increases as the on-ramp metering rate becomes more restrictive. With the implementation of mainline
Figure B-3: Mainline Service Volume = 1850 VPHPL
Downstream Volume in Link 8
Figure B-4: Mainline Service Volume = 1900 VPHPL
Downstream Volume in Link 8

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Figure B-5: Mainline Service Volume = 1950 VPHPL
Downstream Volume in Link 8
metering. Figure B-6 depicts that the average travel speed downstream of the mainline meter increases marginally compared to the ramp metering alone scenarios. These results indicate that, for mainline service volumes of 1,800 vph, mainline metering may provide only marginal benefits over ramp metering for the non-bottleneck condition.

For mainline service volumes of 1,850 vph Figure B-7 indicates that average speed results are very similar to those mentioned above, with two notable exceptions. Both the overall speed and average speed downstream of the mainline meter are slightly lower. Also, when comparing the combined mainline and ramp metering (at four- and five-second metering rate) scenarios with ramp metering alone scenarios, the average speed downstream of the mainline meter has increased by 12 and 9 percent, respectively. However, the overall network travel speeds for these same two scenarios are approximately the same. The above results appear to indicate that mainline metering can increase freeway speed downstream of the mainline meter and the delays incurred upstream of the metering point do not result in any overall travel time increases for the non-bottleneck condition.

The results depicted in Figure B-7 are also true for mainline service volumes of 1,900 vph and 1,950 vph (Figures B-8 and B-9) except for one primary difference. The percent difference in the average speed downstream of the mainline meter between the combined ramp and mainline metering scenario and ramp metering alone scenario increases as the mainline service volume increases.

Figures B-8 and B-9 indicate that, for the ramp metering alone scenario, the increase in mainline volumes results in a decrease in the freeway speed due to the increase in congestion. However, for the mainline meter scenario, the freeway speed downstream of the mainline metering point remains relatively constant and can be controlled based on the desired mainline metering rate. The resulting speed increases downstream of the mainline meter are shown below.

### Percent Increase in Freeway Speed Downstream of Mainline Meter*

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mainline Service Volume</th>
<th>1,900</th>
<th>1,950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Meter 4 Sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainline Meter @1,850</td>
<td></td>
<td>15%</td>
<td>22%</td>
</tr>
<tr>
<td>Mainline Meter @1,800</td>
<td></td>
<td>15%</td>
<td>21%</td>
</tr>
<tr>
<td>Ramp Meter 5 Sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainline Meter @1,850</td>
<td></td>
<td>18%</td>
<td>23%</td>
</tr>
<tr>
<td>Mainline Meter @1,800</td>
<td></td>
<td>17%</td>
<td>22%</td>
</tr>
</tbody>
</table>

*Compared to Ramp Metering Alone Scenario*
Figure B-6: Average Speed For Mainline Service Volume = 1800
Figure B-7: Average Speed For Mainline Service Volume = 1800

Average Speed (mph)

- No Control
- Ramp Meter 3 Seconds
- Mainline Meter 1800 3 Seconds
- Ramp Meter 4 Seconds
- Mainline Meter 1800 4 Seconds
- Ramp Meter 5 Seconds
- Mainline Meter 1800 5 Seconds

Legend:
- ■ Average Speed Downstream of Mainline Meter
- ● Average Speed for Total Network
Figure B-8: Average Speed For Mainline Service Volume = 1900

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Figure B-9: Average Speed For Mainline Service Volume = 1950
According to the above results, the average travel speed for the total network is relatively unchanged when comparing the combined mainline and ramp metering scenarios with the ramp metering alone scenarios within each mainline service volume level. As the mainline demand increases, mainline metering can maintain significantly higher speeds downstream of the mainline meter compared to the ramp metering alone scenarios.

**Travel Time**

Figures B-10 through B-13 present the travel time for each mainline service volume and traffic control scenario simulated. Both the travel time downstream of the mainline meter and the total network travel time are displayed on each figure. The results of the travel time figures are consistent with those presented in the average speed section above. Namely, within each mainline service volume level simulated, the total travel time between the ramp metering alone scenarios and the combined ramp and mainline metering scenarios are approximately the same. The ramp metering alone scenarios experience a decrease in freeway travel time as the metering rate becomes more restrictive. When mainline metering is utilized, freeway travel time downstream of the mainline meter is further reduced. This benefit is almost exactly offset by the additional time spent in the queue upstream of the mainline meter.
Figure B-10: Network Travel Time For Mainline Service Volume = 1800 VPHPL
Figure B-11: Network Travel Time For Mainline Service Volume = 1850 VPHPL
Figure B-12: Network Travel Time For Mainline Service Volume = 1900 VPHPL

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Figure B-13: Network Travel Time For Mainline Service Volume = 1950 VPHPL
APPENDIX C

MAINLINE METERING, CONGESTION PRICING AND
SMART CORRIDORS IMPLEMENTATION

ISSUES SURVEY RESULTS

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Defined below are the three innovative transportation solutions which are the subject of this questionnaire.

**Freeway Mainline Metering**

On many urban freeways, the combination of vehicles traveling on the freeway with vehicles entering and exiting the freeway results in long freeway delays and gridlock conditions. Freeway mainline metering involves controlling the amount of traffic entering a freeway segment to provide improved travel downstream of the control area. This control can be accomplished in a variety of ways including specific geometric designs, or lane use signals regulating when vehicles can proceed into the control section (similar to ramp meter signals). Although the freeway mainline metering approach can result in congestion on the freeway upstream of the control area, it allows for increased travel speed, provides an overall net reduction in travel time, and an increase in traffic volume downstream of the control area.

**Congestion/Peak Period Pricing**

Congestion pricing is a transportation management approach that attempts to spread demand to less congested segments of the network and less congested periods of the day. In essence, users would be charged a toll for using the roadway during peak periods (usually the AM and PM peaks). During the off-peak, travel on the roadway could be free. This is very similar to our long distance telephone operation, in which users are charged a higher phone rate during the day compared to at night or early in the morning.

**SMART Corridors**

SMART corridors involve freeway facilities that are integrated with parallel arterials and frontage roads to obtain the most efficient use of all facilities. With the aid of driver information systems such as variable message signs, highway advisory radio, and possibly in-vehicle navigation systems, the operator or traffic operations center can more effectively manage traffic volumes among all available routes. Traffic signal timings would then be modi-
fied to accommodate the diverted freeway traffic. This type of system is currently being installed along the Santa Monica Freeway in Los Angeles.

1. Given that the traditional ways to manage traffic congestion have not solved our mobility problem, three innovative transportation solutions (defined above) are currently under consideration. Please indicate whether you would strongly favor, somewhat favor, somewhat oppose or strongly oppose each idea. Please circle your response.

<table>
<thead>
<tr>
<th>Strongly Favor</th>
<th>Somewhat Favor</th>
<th>Neutral</th>
<th>Somewhat Oppose</th>
<th>Strongly Oppose</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>57%</td>
<td>30%</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>24%</td>
<td>30%</td>
<td>30%</td>
<td>13%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>83%</td>
<td>10%</td>
<td>7%</td>
<td>——</td>
</tr>
</tbody>
</table>

2. Listed below are possible factors which may affect implementation of the freeway mainline metering, congestion/peak period pricing and SMART corridor concepts. Please indicate the following factors that would affect implementation of the proposed strategies. (Please circle your response for each issue.)

<table>
<thead>
<tr>
<th>Severe Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited Funding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>27%</td>
<td>60%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>7%</td>
<td>53%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>50%</td>
<td>47%</td>
</tr>
</tbody>
</table>
### Lack of Regional Transportation Agency Leadership/Support

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>57%</td>
<td>30%</td>
<td>13%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>83%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>53%</td>
<td>30%</td>
<td>17%</td>
</tr>
</tbody>
</table>

### Lack of State Leadership/Support

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>73%</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>77%</td>
<td>23%</td>
<td>——</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>63%</td>
<td>27%</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Lack of Federal Encouragement/Support

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>47%</td>
<td>40%</td>
<td>13%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>43%</td>
<td>43%</td>
<td>14%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>46%</td>
<td>27%</td>
<td>27%</td>
</tr>
</tbody>
</table>

### Lack of Political Official Leadership/Support

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>53%</td>
<td>37%</td>
<td>10%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>87%</td>
<td>13%</td>
<td>——</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>43%</td>
<td>50%</td>
<td>7%</td>
</tr>
</tbody>
</table>
### Lack of General Public Acceptance/Understanding

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>60%</td>
<td>37%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>90%</td>
<td>10%</td>
<td>——</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>20%</td>
<td>60%</td>
<td>20%</td>
</tr>
</tbody>
</table>

### Difficult Political Official Education Process

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>37%</td>
<td>60%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>54%</td>
<td>43%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>13%</td>
<td>77%</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Lack of Previous Experience

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>10%</td>
<td>67%</td>
<td>23%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>37%</td>
<td>53%</td>
<td>10%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>3%</td>
<td>60%</td>
<td>37%</td>
</tr>
</tbody>
</table>

### Lack of a Demonstration Project

<table>
<thead>
<tr>
<th></th>
<th>Severely Affect Implementation</th>
<th>Somewhat Affect Implementation</th>
<th>Not Affect Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>10%</td>
<td>53%</td>
<td>37%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>27%</td>
<td>47%</td>
<td>26%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>17%</td>
<td>47%</td>
<td>36%</td>
</tr>
</tbody>
</table>
3. In your area, or from your perspective, is a champion/leader necessary to promote/pursue implementation of these transportation solutions?

<table>
<thead>
<tr>
<th>Method</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>93%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>73%</td>
<td>27%</td>
</tr>
</tbody>
</table>

If yes, which agency/individual do you feel would be a more effective champion/leader?

<table>
<thead>
<tr>
<th>Method</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>State DOT Representative</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>44%</td>
<td>42%</td>
<td>7%</td>
<td>7%</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>7%</td>
<td>34%</td>
<td>34%</td>
<td>18%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>37%</td>
<td>63%</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Regional Transportation Agency Representative</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>11%</td>
<td>50%</td>
<td>21%</td>
<td>18%</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>24%</td>
<td>41%</td>
<td>14%</td>
<td>14%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>22%</td>
<td>48%</td>
<td>15%</td>
<td>15%</td>
<td>—</td>
</tr>
</tbody>
</table>
| **Local Politician**
Specify type or position ________________________________ |                |                    |         |                      |                  |
| a. Freeway Mainline Metering  | 30%            | 44%                | 11%     | 11%                  | 4%               |
| b. Congestion/Peak Period Pricing | 59%            | 33%                | 4%      | 4%                   | —                |
| c. SMART Corridors            | 44%            | 40%                | 8%      | 8%                   | —                |
4. When considering implementation of these solutions, which agencies/institutions/individuals should be involved in the planning/education process (i.e., in the form of a steering committee)? Please indicate whether these participants are absolutely necessary, somewhat necessary, or absolutely unnecessary. Please circle your response.

<table>
<thead>
<tr>
<th></th>
<th>Necessary</th>
<th>Neutral</th>
<th>Unnecessary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Local Federal Representative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>90%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>69%</td>
<td>24%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>90%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td><strong>State DOT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>97%</td>
<td>3%</td>
<td>——</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>90%</td>
<td>10%</td>
<td>——</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>100%</td>
<td>——</td>
<td>——</td>
</tr>
<tr>
<td><strong>Regional Transportation Agency Representative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>77%</td>
<td>23%</td>
<td>——</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>87%</td>
<td>13%</td>
<td>——</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>80%</td>
<td>20%</td>
<td>——</td>
</tr>
<tr>
<td><strong>Transit Agency Representative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>43%</td>
<td>40%</td>
<td>17%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>63%</td>
<td>27%</td>
<td>10%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>60%</td>
<td>33%</td>
<td>7%</td>
</tr>
</tbody>
</table>
Necessary | Neutral | Unnecessary
---|---|---
**City Representative**

a. Freeway Mainline Metering | 67% | 27% | 6%
b. Congestion/Peak Period Pricing | 83% | 17% | ——
c. SMART Corridors | 90% | 10% | ——

**Political (Mayor, Supervisor) Representatives**

a. Freeway Mainline Metering | 46% | 36% | 18%
b. Congestion/Peak Period Pricing | 83% | 17% | ——
c. SMART Corridors | 59% | 34% | 7%

**Interest Groups (specific to each area, i.e., trucking, AAA, etc.)**

a. Freeway Mainline Metering | 66% | 28% | 6%
b. Congestion/Peak Period Pricing | 90% | 10% | ——
c. SMART Corridors | 59% | 38% | 3%

5. Would some form of legislative direction/mandate or policy support be necessary or helpful in the decision-making process for these types of transportation solutions?

| YES | NO |
---|---|
a. Freeway Mainline Metering | 69% | 31%
b. Congestion/Peak Period Pricing | 97% | 3%
c. SMART Corridors | 66% | 34%
If yes, who does it need to come from?

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Governor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>24%</td>
<td>32%</td>
<td>36%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>53%</td>
<td>27%</td>
<td>17%</td>
<td>3%</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>26%</td>
<td>33%</td>
<td>33%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Mayor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>25%</td>
<td>38%</td>
<td>25%</td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>60%</td>
<td>24%</td>
<td>10%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>30%</td>
<td>39%</td>
<td>22%</td>
<td>9%</td>
<td>—</td>
</tr>
<tr>
<td><strong>Federal Agency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>46%</td>
<td>37%</td>
<td>17%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>33%</td>
<td>32%</td>
<td>32%</td>
<td>3%</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>52%</td>
<td>39%</td>
<td>9%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>State Agency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>72%</td>
<td>20%</td>
<td>8%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>45%</td>
<td>34%</td>
<td>21%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>65%</td>
<td>30%</td>
<td>5%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Regional Transportation Agency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>40%</td>
<td>32%</td>
<td>20%</td>
<td>8%</td>
<td>—</td>
</tr>
</tbody>
</table>
Regional Transportation Agency (Cont.)

b. Congestion/Peak Period Pricing  
   - Strongly Agree: 55%
   - Somewhat Agree: 28%
   - Neutral: 10%
   - Somewhat Disagree: 7%
   - Strongly Disagree: —

c. SMART Corridors  
   - Strongly Agree: 48%
   - Somewhat Agree: 26%
   - Neutral: 17%
   - Somewhat Disagree: 9%
   - Strongly Disagree: —

Legislative Branch

Specify _________________________  
(i.e., State Assembly or Senate, Federal Transportation Committee, etc.)

a. Freeway Mainline Metering  
   - Strongly Agree: 43%
   - Somewhat Agree: 35%
   - Neutral: 13%
   - Somewhat Disagree: 9%
   - Strongly Disagree: —

b. Congestion/Peak Period Pricing  
   - Strongly Agree: 55%
   - Somewhat Agree: 28%
   - Neutral: 10%
   - Somewhat Disagree: 7%
   - Strongly Disagree: —

c. SMART Corridors  
   - Strongly Agree: 38%
   - Somewhat Agree: 43%
   - Neutral: 14%
   - Somewhat Disagree: 5%
   - Strongly Disagree: —

6. Please indicate how effective you think each of the following would be toward educating/convincing your decision makers that freeway mainline metering, congestion/peak period pricing and/or SMART corridors will better manage traffic congestion. Please circle your response.

   Strongly Agree | Somewhat Agree | Neutral | Somewhat Disagree | Strongly Disagree

Statements From Traffic Experts

a. Freeway Mainline Metering  
   - Very Effective: 33%
   - Somewhat Effective: 50%
   - Neutral: 17%
   - Somewhat Ineffective: —
   - Very Ineffective: —

b. Congestion/Peak Period Pricing  
   - Very Effective: 13%
   - Somewhat Effective: 27%
   - Neutral: 43%
   - Somewhat Ineffective: 10%
   - Very Ineffective: 7%

c. SMART Corridors  
   - Very Effective: 30%
   - Somewhat Effective: 57%
   - Neutral: 13%
   - Somewhat Ineffective: —
   - Very Ineffective: —
<table>
<thead>
<tr>
<th>Local Demonstration Project</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>67%</td>
<td>20%</td>
<td>7%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>47%</td>
<td>33%</td>
<td>7%</td>
<td>13%</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>77%</td>
<td>20%</td>
<td>—</td>
<td>3%</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Previous Experience or Guidelines From Other Areas</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>20%</td>
<td>60%</td>
<td>17%</td>
<td>3%</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>13%</td>
<td>54%</td>
<td>23%</td>
<td>10%</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>27%</td>
<td>60%</td>
<td>13%</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corridor Planning Studies (with use of steering committee and focus groups)</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>17%</td>
<td>57%</td>
<td>20%</td>
<td>6%</td>
<td>—</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>7%</td>
<td>50%</td>
<td>30%</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>19%</td>
<td>58%</td>
<td>13%</td>
<td>7%</td>
<td>3%</td>
</tr>
</tbody>
</table>
7. Please indicate how effective you think each of the following would be toward educating/convincing the public that freeway mainline metering, congestion/peak period pricing and/or SMART corridors will better manage traffic congestion. Please circle your response.

<table>
<thead>
<tr>
<th>Statements From Traffic Experts</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>17%</td>
<td>40%</td>
<td>40%</td>
<td>—</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>7%</td>
<td>23%</td>
<td>37%</td>
<td>23%</td>
<td>10%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>20%</td>
<td>53%</td>
<td>27%</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Local Demonstration Project</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>63%</td>
<td>20%</td>
<td>7%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>50%</td>
<td>20%</td>
<td>17%</td>
<td>13%</td>
<td>—</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>70%</td>
<td>27%</td>
<td>—</td>
<td>3%</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Previous Experience or Guidelines From Other Areas</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>17%</td>
<td>43%</td>
<td>23%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>10%</td>
<td>33%</td>
<td>20%</td>
<td>30%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>13%</td>
<td>54%</td>
<td>23%</td>
<td>10%</td>
<td>—</td>
</tr>
</tbody>
</table>
8. Please indicate the methods you think would be most effective in communicating these potential solutions to the public. Please circle your response.

<table>
<thead>
<tr>
<th>Method</th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Meetings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>13%</td>
<td>47%</td>
<td>23%</td>
<td>7%</td>
<td>10%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>20%</td>
<td>34%</td>
<td>20%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>13%</td>
<td>50%</td>
<td>30%</td>
<td></td>
<td>7%</td>
</tr>
<tr>
<td><strong>Educational Forums</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>10%</td>
<td>57%</td>
<td>20%</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>10%</td>
<td>54%</td>
<td>23%</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>10%</td>
<td>67%</td>
<td>17%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Media (i.e., newspapers, TV, radio)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>50%</td>
<td>33%</td>
<td>10%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>40%</td>
<td>37%</td>
<td>13%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>50%</td>
<td>47%</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brochures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>13%</td>
<td>37%</td>
<td>30%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>13%</td>
<td>40%</td>
<td>20%</td>
<td>24%</td>
<td>3%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>17%</td>
<td>40%</td>
<td>30%</td>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>
Targeted Public Marketing

<table>
<thead>
<tr>
<th></th>
<th>Very Effective</th>
<th>Somewhat Effective</th>
<th>Neutral</th>
<th>Somewhat Ineffective</th>
<th>Very Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway Mainline Metering</td>
<td>36%</td>
<td>54%</td>
<td>7%</td>
<td>3%</td>
<td>—</td>
</tr>
<tr>
<td>Congestion/Peak Period Pricing</td>
<td>29%</td>
<td>58%</td>
<td>7%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>SMART Corridors</td>
<td>36%</td>
<td>57%</td>
<td>7%</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

9. What conditions do you think must occur/exist before you would implement these types of solutions? Please indicate whether each condition must exist, should exist or is not necessary to exist. Please circle your response.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Must Exist</th>
<th>Should Exist</th>
<th>Not Necessary To Exist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of Funding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway Mainline Metering</td>
<td>68%</td>
<td>32%</td>
<td>—</td>
</tr>
<tr>
<td>Congestion/Peak Period Pricing</td>
<td>43%</td>
<td>40%</td>
<td>17%</td>
</tr>
<tr>
<td>SMART Corridors</td>
<td>71%</td>
<td>29%</td>
<td>—</td>
</tr>
<tr>
<td>Significant Ongoing Congestion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway Mainline Metering</td>
<td>87%</td>
<td>13%</td>
<td>—</td>
</tr>
<tr>
<td>Congestion/Peak Period Pricing</td>
<td>93%</td>
<td>7%</td>
<td>—</td>
</tr>
<tr>
<td>SMART Corridors</td>
<td>50%</td>
<td>47%</td>
<td>3%</td>
</tr>
<tr>
<td>Policy Mandate from the Legislative/Political Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway Mainline Metering</td>
<td>26%</td>
<td>37%</td>
<td>37%</td>
</tr>
<tr>
<td>Congestion/Peak Period Pricing</td>
<td>73%</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>SMART Corridors</td>
<td>14%</td>
<td>43%</td>
<td>43%</td>
</tr>
</tbody>
</table>
Lack of Success with Traditional Solutions

<table>
<thead>
<tr>
<th></th>
<th>Must Exist</th>
<th>Should Exist</th>
<th>Not Necessary To Exist</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>37%</td>
<td>50%</td>
<td>13%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>70%</td>
<td>23%</td>
<td>7%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>17%</td>
<td>63%</td>
<td>20%</td>
</tr>
</tbody>
</table>

10. Would your area be willing to consider a demonstration project of one of the previously described transportation solutions to demonstrate their effectiveness?

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>84%</td>
<td>16%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>44%</td>
<td>56%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>93%</td>
<td>7%</td>
</tr>
</tbody>
</table>

If no, would you be willing to try a demonstration project if some form of incentive (i.e., financial assistance) was provided? If yes, specify the incentive you feel would be necessary.

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Freeway Mainline Metering</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>b. Congestion/Peak Period Pricing</td>
<td>41%</td>
<td>59%</td>
</tr>
<tr>
<td>c. SMART Corridors</td>
<td>87%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Thank you very much for taking the time to complete this questionnaire! Your responses will be very helpful in our study of the issues to address when considering new transportation solutions.

Name: ________________________________

Agency: ________________________________

Position: ________________________________

Phone No.: ________________________________
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
GLOSSARY OF TECHNICAL TERMS


Bottleneck. Physical or geometric features of a street or freeway that reduce the facility’s capacity (or ability to accommodate traffic flow) as compared to other locations on the same facility.

Capacity. The maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period.

Closed-Circuit Television (CCTV). Cameras used to view roadway conditions.

Congestion. Condition of overcrowding on a roadway caused by demand exceeding capacity, manifested by high densities, low speeds, stop-and-go driving, increased delay and high rate of rear-end collisions occurring upstream of the bottleneck.

Congestion Pricing. A system that allows for the collection of peak period roadway charges as a means of managing traffic congestion.

Connector Metering. A form of entrance ramp control used to reduce freeway congestion by managing vehicle flow from freeway-to-freeway connectors. The connector contains a traffic signal that regulates the flow of vehicles on to the mainline freeway.

Corridor Control. A system designed to improve travel flow through freeway corridors by applying traffic management strategies and control measures to travel corridors that can encompass several freeways and arterial streets.

Delay. The additional travel time experienced by a driver or passenger beyond what would reasonably be desired for a given trip.

Demand. The number of vehicles desiring to use a given segment of roadway during a specified unit of time.

Density. The number of vehicles occupying a given length of a lane or roadway usually expressed in vehicles per mile.
**Detector.** A device for indicating the presence of passage of vehicles or pedestrians.

**Downstream.** The direction in which traffic flow is moving.

**Driver Information Systems.** Communication systems designed to provide motorists with the most recent information regarding freeway operating conditions.

**Entrance Ramp Control.** A FMS system designed to regulate the number of vehicles that can access the mainline freeway so that traffic volumes do not exceed the freeway’s capacity.

**Free Flow.** A state of the traffic flow at which motorists can maintain their desired speed with little or no delay.

**Freeway Management Strategies (FMS).** Operational improvements designed to maximize traffic flow for all vehicles using the freeway.

**General-Purpose Lanes.** Freeway lanes that are open for use by all vehicles (e.g., trucks, HOVs, single occupant vehicles).

**Highway Advisory Radio (HAR).** Systems designed to broadcast information on traffic conditions in a particular area to motorists traveling in that area and who have immediate need for the information. Motorists are informed through freeway signs that they can access the broadcast via designated frequencies on their car radios.

**High Occupancy Vehicle (HOV).** Vehicles carrying at least two or more persons per vehicle. HOVs can include cars, vans, buses, trucks, or other vehicles that meet the desired occupancy requirement.

**Incident Management.** A collection of traffic management and control measures designed to identify, respond to and clear a freeway incident to minimize its effects on freeway traffic flow.

**Intelligent Vehicle Highway Systems (IVHS).** IVHS is composed of a number of technologies including computers, communications, control, electronics and systems engineering designed to improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy and promote economic productivity of our transportation system.
**Latent Demand.** The total number of potential users desiring to use a facility (street or freeway) at a given point.

**Level of Service (LOS).** A qualitative measure describing the operating conditions (e.g., speed, travel time, maneuverability, comfort, safety) within a traffic stream. Level of service is usually defined in terms of a six-tiered rating system from A to F, representing the best and worst operating condition respectively.

**Mainline Control.** A system designed to regulate, notify and guide vehicles using the freeway mainline to obtain a more uniform, optimum and efficient flow of traffic along the freeway facility.

**Mainline Metering.** A system designed to control the amount of traffic entering a freeway segment to provide improved travel downstream of the control point.

**Metering.** The concept of regulating the amount of traffic that can enter into a downstream lane or freeway facility.

**Mixed Flow Lanes.** See general-purpose lanes.

**Non-Recurring Congestion.** Congestion that is unpredictable as to both the time and location of occurrence. This type of congestion is usually the result of a freeway incident that creates a temporary bottleneck resulting in a significant amount of congestion.

**Queue.** A line of vehicles or persons.

**Queue Bypass.** A facility that provides a bypass around a queue of vehicles delayed at a ramp meter, mainline control point, toll plaza or other bottleneck location (e.g., bridges, tunnels, ferry landings).

**Ramp Metering.** A form of entrance ramp control used to reduce freeway congestion by managing vehicle flow from arterial on-ramps. An on-ramp contains a traffic signal that regulates the entry of vehicles onto the freeway.

**Real-Time Control.** The processing of information or data in a sufficiently rapid manner so that the results of the processing are available in time to influence the process being monitored or controlled.

**Recurring Congestion.** Congestion that occurs at specific locations during particular
times of the day. Recurring congestion is predictable in nature since it “recurs” at these same locations day after day.

**Ridesharing.** The function of sharing a ride with other passengers in other vehicles. The term is usually applied to carpoools and vanpools.

**Stable Flow.** Levels of service A through E are representative of stable flow. It is characterized by the low density-high speed sides of the flow, speed, density curves.

**Surveillance.** The monitoring of traffic performance and control system operation.

**Throughput.** The number of vehicles that pass a given point on a freeway or roadway in a given time period. Usually expressed in vehicles per hour.

**Unstable Flow.** This is representative of a breakdown in traffic conditions that occurs at the maximum flow boundary of level of service E. Unstable flow is characterized by the high density-low speed sides of the flow, speed, density curves.

**Upstream.** The opposite direction to which traffic flow is moving.

**Variable Speed Control.** A system designed to optimize traffic flow on the freeway mainline by regulating the speed of vehicles on the facility.
BIBLIOGRAPHY


Ju, Rong-Shyang et al. "Techniques for Managing Freeway Traffic Congestion." 


Levinson, Herbert S. "Estimating Behavioral Response to Peak-Period Pricing." 
Transportation Research Record 767, Washington, DC. 1980.


