Supply Management Measures for Alleviating Urban Traffic Congestion

by

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Project & Report submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

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And finally, I would like to express my gratitude and thanks to my parents, sisters, Praveen, and Shilpa for their moral and intellectual support, without which this work would not have been successful.
DISCLAIMER

This is to note that part of the information in this report is referred from the “Workshop Notes on Traffic Congestion Management,” by A.G. Hobeika and Sam Subramaniam, September 1994.
# TABLE OF CONTENTS

1.0 INTRODUCTION 1
   1.1 Status of Transportation in the United States 2
   1.2 Urban Traffic Congestion 3
      1.2.1 The Problem 4
      1.2.2 Types of Congestion 4
      1.2.3 Factors Contributing to Increase in Congestion 5
      1.2.4 Extent of the Congestion Problem 8
      1.2.5 Cost of Congestion 9
   1.3 Overall Research Approach 11
   1.4 Organization of the Report 12

2.0 TRANSPORTATION SYSTEM MANAGEMENT 13
   2.1 Background 13
   2.2 Funding of TSM Programs 15
   2.3 Planning of TSM Programs 17
   2.4 Implementation of TSM Programs 18

3.0 CONGESTION MANAGEMENT TOOLS 21
   3.1 Strategies to Alleviate Traffic Congestion 21
      3.1.1 Transportation Supply Management 23
      3.1.2 Transportation Demand Management 24

4.0 SUPPLY MANAGEMENT TOOLS 27
   4.1 Supply Side Issues to Congestion Management 27
      4.1.1 Traffic Improvements 29
         4.1.1.1 Improved Control Devices 29
         4.1.1.2 Improved Intersections 30
         4.1.1.3 Improved Signals (Computerized) 31
         4.1.1.4 Ramp Metering 34
      4.1.2 Physical Improvements 39
         4.1.2.1 Street Widening 39
         4.1.2.2 Provision of Additional Lanes Without Widening the Freeway 40
         4.1.2.3 New Highways 41
      4.1.3 Maximum Utilization of Existing Facilities 43
         4.1.3.1 One-Way Streets 44
         4.1.3.2 Reversible Traffic Lanes 45
         4.1.3.3 Turn Prohibitions 46
      4.1.4 Arterial Access Management 47
         4.1.4.1 Super Street Arterials 48
         4.1.4.2 Arterial Surveillance and Management 50
      4.1.5 Exclusive Bus Lanes 52
      4.1.6 HOV Lanes 54
      4.1.7 Freeway Incident Detection and Management Systems 61
         4.1.7.1 Freeway Incident Detection 61
         4.1.7.2 Incident Congestion Management 62
4.1.8 Motorist Information Systems
4.1.9 Future Technologies

5.0 CASE STUDIES
5.1 Improved Control Devices
5.1.1 West German Variable Speed Limits
5.1.2 Japan Urban Freeway

5.2 Traffic Signal Improvements
5.2.1 California’s FETSIM
5.2.2 Los Angeles ATSAC

5.3 Improved Intersections
5.3.1 US 70 Corridor

5.4 Ramp Metering

5.5 Super Street Arterials
5.5.1 Houston Super Street Arterial

5.6 Exclusive Bus Lanes
5.6.1 Bangkok Bus Lanes
5.6.2 Exclusive Bus Lanes in Porto Alegre
5.6.3 Comprehensive Transport System in Abidjan, Ivory Coast
5.6.4 Second Avenue Bus Lane, New York
5.6.5 Exclusive Bus Lane Projects in the United States

5.7 Freeway Incident Detection and Management Systems
5.7.1 Illinois Traffic Management
5.7.2 Seattle Area Incident Management
5.7.3 Toronto Traffic Management
5.7.4 Operation of Traffic Management Systems in the United States
5.7.5 Operation of Traffic Management Systems Abroad

5.8 HOV Lanes
5.8.1 Houston Transitway System
5.8.2 I-394 Interim HOV Lane
5.8.3 Shirley Highway Busway

5.9 Future Technologies
5.9.1 Advanced Traffic Management Systems
5.9.2 Advanced Traveler Information Systems
5.9.3 Advanced Vehicle Control Systems

6.0 CONCLUSIONS
6.1 Supply Management Tools for Urban Freeways and Non-Freeways
6.2 Summary

REFERENCES
LIST OF TABLES

Table 1.1  Trip Characteristics (1990)  3
Table 1.2  1990 Roadway Congestion Level  9
Table 1.3  Roadway Congestion Costs  10
Table 4.1  Supply Management Tools  28
Table 4.2  Travel Time Savings Resulting From Traffic Signal Improvements  33
Table 4.3  Summary of Annual Costs of Various Signal Improvements  33
Table 4.4  U.S. Freeway Surveillance and Control Systems  35
Table 4.5  Summary of Benefits of Seven Ramp Metering Systems in the U.S. and Canada  38
Table 4.6  Maximum Observed One-Way Hourly Freeway Volumes  40
Table 4.7  Large Capacity Increase Alternatives  43
Table 4.8  Characteristics of Existing Freeway/Expressway HOV Facilities  57
Table 4.9  Impact of HOV Facilities on Person Movement and Vehicle Occupancy  58
Table 4.10 Reduction in Delay due to Improved Service Parameters  65
Table 5.1  Results of the Average Delay Savings with the Implementation of Closed Loop Systems  81
Table 5.2  Estimated Annual Peak Hour Fuel Savings with Implementation of Closed Loop Systems  82
Table 5.3  Relationship Between Strategies and Tactics  85
Table 5.4  Alternative Regional Arterial Network for Houston Region  90
Table 5.5  Effects of the 350-mile Strategic Arterial System  91
Table 5.6  Effects of the 600-mile Strategic Arterial System  91
Table 5.7  Results of Traffic Studies, 1972  97
Table 5.8  Transit/Carpooling Ridership in HOV Facilities  110
Table 5.9  I-394 HOV Facility Projected Impacts  112
Table 5.10 Traffic Impacts of HOV Lanes  114
Table 5.11 Reported Benefits from ATMS Operational Tests  116
Table 5.12 Reported ATIS Benefits Based on Simulation Models  118
Table 5.13 Operational Tests Overview  120
Table 6.1  Summary of Supply Management Tools  122
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>American Transportation Expenditures, Freight and Passenger, 1990</td>
<td>2</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Main Commuting Flows (1960-1980)</td>
<td>6</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>Factors Affecting Vehicle Travel (1983-1990)</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Total TSM Funding</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Major Federal-Aid Highway Expenditures for Supply Management</td>
<td>16</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>MPO Respondents Reporting Strong or Moderate Emphasis for Supply Management Activities</td>
<td>18</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>MPO Respondents Reporting Strong or Moderate Emphasis in Planning for Supply Management</td>
<td>19</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Framework of Congestion Management Strategies</td>
<td>22</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Conceptual Design for Integration System</td>
<td>84</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Network Total Delay</td>
<td>88</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

1.1 Status of Transportation in the United States

Urban transportation in North America is at a crossroads. Events at the local, national, and international levels during the past decade that have dictated the present transportation situation have not shown any particular direction or stable trend. Transportation engineers, planners and policy makers have been left to sort through the plethora of conflicting policies, programs, and occurrences to evaluate a rational and feasible approach to transportation problems in the United States.

Increased attention is being given to the need for infrastructure replacement in both the areas of highway and transit. Highway transportation has recently risen to the status of a major issue at all levels of government. The condition of this country’s highway infrastructure has been deteriorating for a number of years. The blame can be attributed to a number of factors, the most important one being the funding. There weren’t enough funds to support both transportation and non-transportation projects in the 1970’s, and it was easier to defer maintenance and construction of highways, than to seek additional funding. The physical deterioration has had a negative impact on the quality of service of the highways as well. Although lack of funds was the major factor that hindered attention to the highway system, there were other contributing factors that played a significant role. In the 1970s, environmental concerns dominated transportation policy. Insensitivity to the environment by some highway agencies in the early years of the interstate and other federal-aid programs caused Congress to step in and establish specific rules and regulations for federally-funded programs. Figure 1.1 shows the passenger transportation expenditures for 1990. It is seen that more than $500 billion dollars is spent annually on highway expenditures, which accounts for 17% of the total GNP of the nation. Though
such a great amount of money is spent on highway programs, the improvement of the level of service offered to commuters is insufficient.

![Bar Chart: American Transportation Expenditures Freight & Passenger, 1990](Image)

**Figure 1.1:** American Transportation Expenditures Freight & Passenger, 1990  
(Source: Traffic Impact Analysis, 1990)

Although alternative solutions have been applied continuously, the infrastructure cannot keep in pace with the growing population, flourishing economy, and the number of vehicles per household. Table 1.1 gives a description on the increase in demographics and number of vehicle trips over the years. As the statistics in the table indicate, it is obvious that there has been a steady increase in vehicle trips traveled, thus resulting in a subsequent increase in person miles of travel from 1969 to 1990. This situation further intensifies the state of the current transportation system - increased traffic congestion.
Table 1.1: Trip Characteristics, 1990

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Household Veh. (thousands)</td>
<td>72,500</td>
<td>120,098</td>
<td>143,714</td>
<td>165,221</td>
</tr>
<tr>
<td>Household Veh. Trips (miles.)</td>
<td>87,284</td>
<td>108,826</td>
<td>126,874</td>
<td>158,927</td>
</tr>
<tr>
<td>Household VMT (miles)</td>
<td>775,940</td>
<td>907,603</td>
<td>1,002,139</td>
<td>1,409,600</td>
</tr>
<tr>
<td>Person Trips (miles)</td>
<td>145,146</td>
<td>211,778</td>
<td>224,385</td>
<td>249,562</td>
</tr>
<tr>
<td>Person Miles of Travel (miles)</td>
<td>1,404,137</td>
<td>1,879,662</td>
<td>1,946,662</td>
<td>2,315,300</td>
</tr>
</tbody>
</table>

(Source: National Personal Transportation Survey-Summary of Travel Trends, 1990)

1.2 Urban Traffic Congestion

Congestion occurs when the demand on the road network exceeds its capacity to carry traffic. This results in the slow movement of traffic and increased economic costs, particularly in terms of lost productivity and increased energy consumption. Today, dealing with congestion is one of the major issues of concern for all transportation professionals. With the birth of modern science in traffic engineering and management, we have attempted to introduce technology to the solution of these problems. Yet, our traffic growth and the resulting congestion usually have been far ahead of our ability to manage it. The situation has worsened due to the increase in automobile ownership and the population growth, and decrease in average vehicle occupancy, which results in an increase in vehicle ownership and vehicle miles traveled. Traffic congestion has become a major problem for workers and businesses, slowing down the delivery of goods and services and the movement of people, thereby impeding the very mobility needed for economic expansion.
1.2.1 The Problem

Traffic growth is greatly exceeding the growth in road supply, and the situation is worsening. It is predicted that traffic will continue to increase by 50% by the year 2005, but road supply will only increase by 5%. The results of this great difference, unless adequately addressed, will be a 400% increase in deterioration, and continued decays in operational efficiency, safety, air quality, and productivity. Some interesting statistics of urban areas under severe congestion are listed below:

- California leads the nation in motor vehicle ownership with 19 million motor vehicles registered. Congestion in metropolitan areas is California’s most serious problem. Predictions are that traffic congestion in Alameda county will increase 150% unless action is taken.

- North Carolina reported that the number of urban miles of travel increased by 132% between 1970 and 1985. The number of congested intersections in Charlotte grew from 40 to 123 from 1980-1987.

- In Metropolitan Washington D.C, the percentage of peak hour vehicle miles operated under significantly congested conditions to climb from 40% in 1980 to over 60% in 2005, although current plans for alleviation are implemented.

1.2.2 Types of Congestion

Congestion may be classified into two kinds:

Recurrent congestion typically occurs everyday during peak periods due to the demand exceeding the capacity of a section of highway. This congestion often results from traffic moving between work and home during “rush” hours.

Non-recurrent congestion typically results from an incident or other event that blocks freeway lanes or otherwise reduces capacity. It is estimated that non-recurrent congestion accounts for over 60% of urban freeway congestion in the U.S.
1.2.3 Factors Contributing to Increase in Congestion

The main causes for the increase in congestion can be contributed to the following:

*Population Growth*

Americans today predominantly live in metropolitan areas. More than 75% of the population lives in these areas. Some key facts about metropolitan areas that illustrate the population growth in these areas are:

- Between 1950 and 1986, population increased from 23% to 44%.
- Since 1950, 86% of the U.S. population growth occurred in suburban areas.
- Between 1960 and 1990, central city population increased by 37% while suburban population increased by 126%.

*Suburban Shift*

Suburban shift is characterized by both massive shifts of jobs to the suburbs and by a significant increase in the density of suburban employment. Almost two-thirds of all jobs created between 1960 and 1980 were located in suburban areas. The result of this suburban growth has been an explosion in the number of suburban trips made in our metropolitan areas. Figure 1.2. shows the increase in the number of trips made from suburb to suburb from 1960 to 1980.

Of the total growth in the commuting trips in the U.S. between 1960 and 1980, suburban commuting accounted for 83 percent. This dispersed nature of travel origin and destination is the major cause for significant increases in traffic congestion observed on roads that primarily serve non-center city-oriented trips.
Figure 1.2: Main Commuting Flows
(Source: CIA)

Increase in Automobile Use

It is a known fact that the automobile is a predominant mode of transportation in the United States in urban areas. The increase in the number of automobiles on the road is the result of three main factors—the increased number of households, the increased number of automobiles available per household, and the decline of other means of transportation. As mentioned earlier, due to the rapid growth in population, there has been an equal amount of increase in the households giving rise to an increase in the number of people entering the work force. The number of vehicles per household rose from 0.85 in 1960 to 1.34 in 1980. This factor is very important in explaining the propensity for the automobile-dominated work trip, which is due to the following:

- The increase in vehicle trips by 25% between 1983 and 1990 and increase in vehicle miles traveled by 40%, both doubling the person travel trend.
- The 40% increase in vehicle miles of travel can be attributed to the following facts:
  - A cumulative effect of three factors--7 percent increase in person trips per person, 5 percent increase due to shifts in modal split, and 6 percent increase due to vehicle occupancy changes--resulted in a 20% increase in vehicle trips per capita.
  - The vehicle miles per capita, coupled with a 4% increase in population results in a 25% increase in vehicle trips.
  - And finally an increase of 12% in vehicle trip length contributes to the final increase of 40% in Vehicle Miles Traveled (VMT).

Figure 1.3 gives the percent increases of the factors affecting vehicle travel based on the explanation stated above.

![Factors Affecting Vehicle Travel (1983-1990)](image)

**Figure 1.3:** Factors Affecting Vehicle Travel (1983-1990)
(Source: National Personwide Transportation Survey-Travel Behavior Issues in the 1990s)
1.2.4 Extent of the Congestion Problem

Knowing the factors that increase the level of congestion in urban areas, it is important to have a factor to measure congestion. To determine the magnitude of this problem and to identify congestion levels, a quantifying measure known as Roadway Congestion Index (RCI) was deemed appropriate.

The RCI is based on research indicating that urban area roadway congestion can be estimated using freeway and principal arterial daily vehicle-miles of travel (DVMT) per lane-mile. The RCI utilizes daily values since they represent readily available data that are normally collected as part of the transportation planning process throughout the U.S. When area-wide freeway travel volumes reach 13,000 DVMT per lane-mile, the beginning of congested conditions (level of service D) is estimated to occur. For principal arterial streets, the corresponding level of service is represented by a system of an average of 5,000 DVMT per lane mile. Gauging the existing freeway and principal arterial DVMT versus these thresholds produces a value which can be used as an indicator of relative mobility in urban areas (equation below).

\[
\text{RCI} = \frac{[\text{Freeway DVMT/Ln-Mile} \times \text{Freeway DVMT} + \text{Prin Art. DVMT/Ln-Mile} \times \text{Pric Art Str DVMT}]}{[13,000 \times \text{Freeway DVMT} + 5,000 \times \text{Pric Art Str DVMT}]} 
\]

Some key points about the equation above:

- The numbers in the denominator indicate the level of VMT per lane mile at which the congestion begins.
- An RCI > 1 indicates area wide congested conditions.
- An RCI < 1 indicates that average metropolitan mobility is uncongested although there still could be some spots with serious congestion.
Table 1.2 represents the eleven most congested urban areas in the United States. The RCI values range from 1.55 (Los Angeles) to 1.12 (Houston and New Orleans). All of these cities have surpassed the RCI value of 1.0 at which undesirable levels of congestion occurs.

<table>
<thead>
<tr>
<th>Areas</th>
<th>Freeway</th>
<th>Arterial</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DVMT (thou.)</td>
<td>DVMT (Ln-Mi)</td>
<td>DVMT (thou.)</td>
<td>DVMT (Ln-Mi)</td>
<td>RCI</td>
<td>Rank</td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>110, 350</td>
<td>21, 100</td>
<td>80, 370</td>
<td>6, 480</td>
<td>1.55</td>
<td>1</td>
<td></td>
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<tr>
<td>Washington D.C.</td>
<td>25, 340</td>
<td>16, 610</td>
<td>19, 560</td>
<td>8, 500</td>
<td>1.37</td>
<td>2</td>
<td></td>
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<tr>
<td>San Francisco</td>
<td>42, 590</td>
<td>17, 820</td>
<td>14, 000</td>
<td>6, 110</td>
<td>1.35</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Oak.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Miami</td>
<td>8, 570</td>
<td>14, 170</td>
<td>15, 810</td>
<td>7, 620</td>
<td>1.26</td>
<td>4</td>
<td></td>
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<td>Chicago</td>
<td>38, 030</td>
<td>15, 680</td>
<td>29, 050</td>
<td>6, 980</td>
<td>1.25</td>
<td>5</td>
<td></td>
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<tr>
<td>San Diego</td>
<td>27, 690</td>
<td>16, 050</td>
<td>9, 340</td>
<td>5, 460</td>
<td>1.22</td>
<td>6</td>
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<td>Seattle</td>
<td>18, 920</td>
<td>15, 640</td>
<td>9, 130</td>
<td>5, 800</td>
<td>1.20</td>
<td>7</td>
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<td>San Bernardino</td>
<td>14, 580</td>
<td>16, 290</td>
<td>10, 150</td>
<td>4, 740</td>
<td>1.19</td>
<td>8</td>
<td></td>
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<td>New York</td>
<td>82, 920</td>
<td>14, 050</td>
<td>52, 060</td>
<td>6, 890</td>
<td>1.14</td>
<td>9</td>
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<tr>
<td>Houston</td>
<td>28, 230</td>
<td>14, 700</td>
<td>10, 830</td>
<td>5, 080</td>
<td>1.12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>New Orleans</td>
<td>4, 970</td>
<td>13, 810</td>
<td>4, 100</td>
<td>6, 560</td>
<td>1.12</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

(Source: Estimation of Urban Congestion, Texas Transportation Institute, 1993)

1.2.5 Cost of Congestion

This is another method of evaluating the impact of congestion that is directly related to the economy of the nation. The two main costs resulting from congestion are the costs of lost productivity due to increased time people spend traveling and excess energy consumption due to delays. The degree of congestion decreases the vehicle speed and increases the fuel consumption by decreasing the vehicle fuel efficiency. Some interesting facts on the cost of congestion include:

- Current costs due to congestion are estimated to be about $40 billion dollars.
- Congestion on urban freeways resulted in delays of 460 million vehicle hours in 1983 and 722 million vehicle hours in 1985.
• It is estimated that in the year 2005 over 12,000 million vehicle hours will be lost due to congestion.
• By the year 2002, over 12,000 million gallons of fuel will be wasted due to traffic congestion.
• Average per capita costs from congestion in U.S urban areas were estimated to be $310 in 1989.

Some of the highest costs of congestion in the cities in the United States are as follows:

Los Angeles--$7.67 billion
New York--$6.56 billion
San Francisco-Oakland--$2.81 billion
Washington D.C.--$2.37 billion
Chicago--$2.29 billion

Table 1.3 depicts the vehicle hours of delay and the average congestion cost for different regions of United States. The total average for the country was $310/capita in 1989.

Table 1.3: Roadway Congestion Costs, 1989

<table>
<thead>
<tr>
<th>Urbanized Areas</th>
<th>Daily Vehicle Miles of Travel</th>
<th>Vehicle Hours of Delay</th>
<th>Congestion Cost</th>
<th>Delay and Fuel Cost (Mil. Dol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Miles (1,000)</td>
<td>Per-lane-mile of Fwy</td>
<td>Total Hours</td>
<td>Per 1000 persons</td>
</tr>
<tr>
<td>Northeastern Cities</td>
<td>25,060</td>
<td>12,550</td>
<td>419,930</td>
<td>90</td>
</tr>
<tr>
<td>Midwestern Cities</td>
<td>13,790</td>
<td>11,570</td>
<td>111,990</td>
<td>40</td>
</tr>
<tr>
<td>Southern Cities</td>
<td>6,940</td>
<td>11,790</td>
<td>84,310</td>
<td>80</td>
</tr>
<tr>
<td>Southwestern Cities</td>
<td>9,640</td>
<td>11,430</td>
<td>105,160</td>
<td>70</td>
</tr>
<tr>
<td>Western Cities</td>
<td>27,070</td>
<td>15,310</td>
<td>385,570</td>
<td>130</td>
</tr>
<tr>
<td>Total Average</td>
<td>15,340</td>
<td>12,400</td>
<td>196,750</td>
<td>80</td>
</tr>
</tbody>
</table>

(Source: Texas Transportation Institute: Roadway Congestion in Major Urban Areas)
1.3 Overall Research Approach

With a brief overview on the definition of congestion, its measures, and effects, the research concentrates on the analysis of low-cost reduction strategies for alleviating congestion in urban areas. With the advent of new technologies, the approaches are becoming more readily available and working in real time; however that does not eliminate the traditional methods which have been in practice for years. Especially in urban areas, where free land is very scarce for construction of new highways to provide additional capacity, the effective use of existing facilities is a common approach.

The approach used in this study involved a review of the current and future supply management tools available for combating congestion. These tools were carefully selected and grouped based on the type of improvement they offered in reducing congestion. A strong emphasis was given to the benefits, costs and implementation issues of the tools based on previous research and applications of the strategies. To substantiate the extent of the improvements these strategies offer to alleviating congestion, case studies were discussed in both developing and developed countries. Finally, a summary of these tools is described to provide a brief overview.

An important issue to consider when suggesting alternative approaches to relieve congestion is that no single approach would ever be suitable to apply to the existing problem. It is thus necessary to balance the approaches to reduce congestion, whether it is by increasing capacity or reducing the demand for automobile use. That is why transportation professionals have come up with various approaches to attain this balance. A key issue to consider during implementation of these measures is the fact that we can not always account for all the effects that occur in our daily lives, such as, the increase in population, developing economy, and subsequently in the vehicle miles traveled. With a
description of the strategies employed, their benefits and their implementation issues, the project also discusses practical applications of these measures for future operations.

1.4 Organization of the Report

This chapter has briefly discussed the urban congestion problem, its measures, and effects. Following this, chapter 2 discusses Transportation Systems Management (TSM) describing the definition, planning, funding, and implementation issues. An overall review of the available measures, both demand and supply measures, for mitigating congestion, is presented in Chapter 3. This section gives a brief description of transportation supply management and transportation demand management.

Chapter 4 presents a general inventory of supply management strategies for alleviating congestion. Also included in this section of the report is the identification of costs, benefits, and implementation issues associated with these strategies. In Chapter 5, several case studies are identified and their benefits discussed to evaluate practical applications of the strategies discussed in the earlier chapter. Finally, Chapter 6 gives a summary and an assessment of these supply measures and discusses future potential applications and impacts to combat congestion in urban areas.
2.0 TRANSPORTATION SYSTEMS MANAGEMENT

Transportation Systems Management (TSM) is the name given to the concept of increasing the productivity of transportation systems by means other than large-scale construction. TSM embraces a host of measures, all with the purpose of seeking to achieve better results from existing facilities rather than creating new highways and transit systems. These measures tend to be subtle, low-cost, and have a short time frame compared to new capital construction. TSM includes transportation supply management techniques, such as ramp metering and traffic signal coordination, as well as transportation demand management techniques, such as promoting carpooling and vanpooling.

2.1 Background

In the last 20 years, TSM techniques have repeatedly demonstrated their effectiveness. On the supply side, evaluations of traffic signal coordination systems continue to show positive cost benefits, while on the demand side, ride sharing and vanpooling are producing the same amount of benefits. Several of the ensuing surface transportation reauthorizations supported various strategies for transportation systems management. Although no specific incentives were included in the 1987 Surface Transportation Act, the 1990 Clean Air Act did contain several TSM-related provisions for controlling emissions from vehicles.

Transportation Systems Management (TSM) was first introduced in the joint Urban Mass Transportation Administration (UMTA)/Federal Highway Administration (FHWA) planning regulations of 1975. This change was proposed to shift the nation’s focus from high-capital approaches to meet transportation needs to a greater consideration of low-capital-intensive solutions to such needs. The TSM concept calls upon local agencies to
consider, in the spirit of cooperative decision making, a range of low-cost investment requirements that can improve transportation services in the short term. The concept reflects a growing concern that increasing congestion, steeply rising environmental concerns, and intense competition for available resources make it imperative that better and more efficient uses of existing investments in the transportation infrastructure be found before additional investments are made in costly new facilities.

During the past few years, TSM has evolved in a number of ways, reflective of the variety of local circumstances in which it has occurred. There is no one planning organization or organizational arrangement which can fit the diversity of metropolitan areas in the United States. The function of TSM planning is to foster the use of the combination of modes that best represents an area's design and balance between the goals of efficient mobility, environmental attractiveness, and social equity in the operation of its transportation system. However, the full potential of TSM is still far from being realized. Translating this concept into system wide strategies has proven to be difficult, and thus most agencies have decided to examine TSM projects which have been already implemented so as to get a better idea to plan and implement further projects. The impacts due to the implementation of the TSM projects would also give us a perspective on the expected impacts of future projects.

It has become apparent that the most important characteristics of a transportation program is the planning and funding of the program. TSM planning does not only involve one urban area but a number of diverse groups and consists of various actors. This multifaceted characteristic of the TSM program was considered to include flexibility into the recommended framework by the provision of an important place for subarea or local TSM studies.
2.2 Funding of TSM Programs

The federal-aid highway program constitutes the basic source of federal funding that the states use for all highway projects, including TSM projects. A considerable amount of federal-aid funds have been used to support TSM activities, although the overall amount is small compared to federal-aid highway funding. Approximately $1 billion was spent on various supply and demand projects from 1980-1989. Adding major high-occupancy vehicle lanes to this estimate raises total TSM funding to approximately $1.6 billion. Figure 2.1 below shows the split between the various categories in TSM, the supply measures, demand measures, and HOV lanes.

![Total TSM Funding](image)

**Figure 2.1: Total TSM Funding**
(Source: General Accounting Office: Transportation System Management, 1991)

No state used more than 3% of its federal-aid on TSM projects during the 1980's. Most of the TSM funding was used for supply management projects, principally traffic signals and computerized programs to run them. The other major share was allocated for the addition of HOV lanes. An even further split of the funding expenditures for supply management projects is shown in Figure 2.2. It is again realized that traffic signal
improvements are the measure which is concentrated on mostly, and, from past experiences, the improvements in this strategy have brought the greatest payoffs.

![Major Federal-Aid Highway Expenditures for Supply Management](image)

**Figure 2.2:** Major Federal-Aid Highway Expenditures for Supply Management

(Source: General Accounting Office: Transportation System Management, 1991)

Though the funding provision had tried to provide some incentives to increase the expenditures on more TSM projects, there was a general consensus among state departments of transportation officials that the incentive was not to add more money to TSM projects but rather, the reassignment of existing federal funding, as the incentive was to be used for railroad crossings and highway safety. Presently, the more urgent needs of metropolitan cities is faster mobility due to recurring and non-recurring congestion conditions.
2.3 Planning of TSM Programs

In addition to funding, metropolitan planning constitutes an important way in which the federal government could encourage the local adoption of TSM techniques. Metropolitan planning organizations were established by the federal government to improve local intergovernmental coordination in transportation. For almost 30 years, the federal government has been involved in metropolitan planning through its requirement that transportation planning be conducted before federal-aid funds are disbursed. Therefore, the transportation planning process represents a second area where the federal government could encourage consideration of TSM.

In 1975, MPO's were given responsibility for long-range transportation planning and were required to formulate a separate TSM element into their plans. In order to better understand how transportation planning relates to local TSM implementation, a survey of 119 metropolitan cities was conducted, and the responses received stated that most of the TSM projects were considered short range. Almost all the responding MPO's noted that their regional plans have placed at least a moderate emphasis on some type of TSM improvement. Of the various TSM techniques, two supply management activities, signal improvements and restriping and widening, received the most attention, with over 70% of the MPO's noting that at least a moderate emphasis has been placed on these techniques. In comparison, none of the demand management activities received such universal attention in regional plans; the most considered was ridesharing, with approximately 38% of MPO's placing at least a moderate emphasis on this activity. The following (Figure 2.3) shows the emphasis placed on different activities of the supply tools by the survey.
Figure 2.3: MPO Respondents Reporting Strong or Moderate Emphasis for Supply Management Activities
Source: (General Accounting Office: Transportation System Management, 1991)

2.4 Implementation of TSM Programs

In general, metropolitan areas place a strong emphasis in implementing the supply measures compared to planning them. Comparatively, demand management receives consistently less emphasis in implementation than in planning. Figure 2.4 shows the emphasis metropolitan planning organizations place on planning and implementation of supply management measures.

One of the critical problems facing effective transportation planning is the often consequential link between planning and implementation. A more direct connection should be established between the TSM planning and implementation process. This would involve developing a local planning process that highlights low-cost approaches to congestion mitigation and identifies TSM activities as first priority or more certain funding.
once they have been incorporated in these regional congestion management or clean air plans.

![Bar chart showing emphasis on various transportation management strategies](image)

**Figure 2.4: MPO Respondents Reporting Strong or Moderate Emphasis in Planning for Supply Management**

Source: (General Accounting Office: Transportation System Management, 1991)

From all the review, it is shown that the federal government plays a key role in facilitating local consideration of low-cost traffic management techniques. However, current efforts are still not very effective in achieving widespread TSM objectives. Given the growing concerns of traffic congestion, air quality, and energy consumption, there is sufficient basis for encouraging traffic management techniques. Concern should be given to ensure that the current federal policy should contain measures with sufficient strength to achieve the desired transportation efficiency.
The following chapter discusses the various congestion management strategies available to relieve urban traffic congestion. With a brief description of the supply and demand measures, we will continue to discuss the key supply strategies and their implementation issues used to combat congestion.
3.0 CONGESTION MANAGEMENT TOOLS

3.1 Strategies to Alleviate Traffic Congestion

Traffic congestion has reemerged in the 1980s as a leading public concern. Throughout the United States, reports on the long queues and daily tie-ups appear on a regular basis. Highway agencies and transit operators are castigated for failing to provide the facilities and services needed to assure a convenient commute. The agencies, in turn, point to funding cutbacks and escalating costs as a barrier to action. Urbanists and demographers note that decentralized development patterns and increased population in the work force have both contributed to the growth of congestion. Angry citizens look to the transportation officials to provide them with answers or find solutions to relieve congestion.

So what are the strategies available for alleviating traffic congestion? When this discussion comes into picture, the most immediate solutions are those which would allow more efficient use of the existing transportation infrastructure. Techniques such as retiming and coordination of traffic signals, ramp metering, and freeway management can be very effective in increasing capacity of the existing system. There are also techniques which control demand by encouraging carpools, vanpools, and mass transit systems. Both the supply and demand measures are short term solutions and do not attack the root of the problem. The long term solution and the last alternative lies in making land use strategies, which is also the most difficult to implement. These strategies deal with structuring communities so that people live closer to their jobs and do not need to rely so heavily on their cars for other activities.
The figure 3.1 shows the framework of the division of management tools available for alleviating congestion. A brief description of the transportation supply management and transportation demand management will be discussed below.

Figure 3.1: Framework of Congestion Management Strategies
An emphasis on various transportation supply management measures available, their benefits, and implementation issues is described in Chapter 4. A brief overview of these strategies is provided in the following section.

3.1.1 Transportation Supply Management

Transportation Supply Management is a short range element of a regional transportation process that addresses ways to improve overall transportation system performance through various low-capital or no-capital management actions. The goal is to increase the capacity without significant new infrastructure investment, rather than to simply accommodate increasing vehicle travel by adding more roads. It embraces a host of measures all with the purpose of seeking to achieve better results from existing facilities, rather than by creating new highways and transit systems. These measures are low cost and can be implemented in a short time frame as compared to measures like new construction.

Common tactics used to ease congestion is either adding new facilities or improving the existing facilities with operational changes. From the cost point of view, it is not beneficial to build more highways to increase capacity as a means of alleviating congestion. The availability of land is also very scarce in densely populated urban areas where the congestion problems are the most intense. Supply Management aims to reduce congestion using low cost modifications, such as improved traffic signalization techniques, utilization of existing facilities like one way streets, reversible lanes, turn prohibitions, etc. It also aims to develop actions for non-recurring congestion, such as incident detection programs, motorist information systems, etc.

The federal highway administration and local highway agencies are mainly responsible for the successive implementation of the above strategies. Approximately $954 million of the
federal aid was given to implement supply management measures out of which $827 million has been spent on various projects. Most of the funding was concentrated on improvements to traffic signals and advanced technologies.

As supply management tools are very specific, based on the location and facility, a well implemented program could result in significant increases in capacity with moderate to minimal cost. Other measures of effectiveness for supply tools are vehicle speed, travel time savings, reductions in delays and stops, and reductions in accidents. The supply management tools are discussed in detail following this introduction to provide an overview of the effective strategies based on the results of implemented projects.

3.1.2. Transportation Demand Management

Traffic demand management (TDM) comprises those actions designed to alleviate congestion by decreasing the volume of traffic and vehicle miles traveled. Put another way, these tools seek to maintain a favorable volume to capacity ratio on the road network through actions which reduce traffic volume rather than through expanding road capacity. TDM strategies can be classified in four ways:

- Spatial response strategies divert traffic to under-utilized routes.
- Temporal response strategies spread demand to off-peak hours.
- Modal response strategies encourage increases in vehicle occupation and use of public transit.
- Total response strategies concentrate on combining or eliminating trips altogether.

Implementing an effective TDM program requires that commuters have a choice of travel alternatives, incentives provided to them to use those alternatives, and that the private sector supports and participates in the program. A well implemented TDM program can result in a 10% to 15% shift in mode of travel, from single occupancy vehicles to high
occupancy vehicles or transit. Federal funding for TDM programs went primarily (85%) for rideshare programs, including car pool facilities, computer ride matching, and van pool programs. The remainder went to pedestrian and bicycle facilities improvements (15%) and auto restricted zones (1%).

Evaluation of TDM programs requires that the program has a stated goal at its outset. There are four possible goals for TDM programs:

- **Participation Rate**: The objective is to decrease the percentage of single occupancy vehicle (SOV) commute trips. The emphasis is on persuading drivers to change travel modes.

- **Vehicle Trip Reduction**: The objective is to reduce the number of vehicle trips. This is measured by a percentage change in overall traffic volume.

- **Peak Hour Vehicle Trip Reduction**: The objective is to reduce vehicle trips during a specified peak hour.

- **Level of Service**: The objective is to maintain a designated LOS for specified road facilities.

In addition to reducing congestion, a TDM goal also can be to improve urban air quality. TDM program costs and benefits are distributed among travelers, employers and government (the public). In addition to money saved on direct transportation costs, benefits from TDM programs include increased mobility and decreased pollution. While TDM actions can be directed at all drivers, they often target those drivers commuting to work. This is because morning and evening peak periods, when the most traffic is on the roads, are caused by commuters and because commute trips, due to their regularity and consistent origins and destinations, are the easiest to affect through TDM actions.

It should be remembered though that to effectively reduce congestion it is important to apply these strategies as a package. This package, however, cannot be a random
combination of tools. The tools must be selected based on the congestion situation and the environment in which they need to be implemented. These tools should also be mutually supportive in order to eliminate any conflict between them. Recently, much interest has been on the various demand strategies which can be implemented to urge people to rideshare and carpool, but improvements on the supply side have not been given enough consideration. The focus of this project is to study the potential supply management alternatives offer in congestion reduction. The remaining chapters thus concentrate on this issue.
4.0 SUPPLY MANAGEMENT TOOLS

The previous chapter discussed the importance of Transportation System Management in the transportation planning process. This chapter describes the various supply management tools applicable to reduce congestion effectively. The strategies discussed below represent the most promising techniques by which urban area congestion can be alleviated both at present and in the foreseeable future. The following will discuss a description of the tool, its benefits, and implementation issues.

4.1 Supply Side Issues to Congestion Management

Though urban freeway congestion of two significant types, recurring and nonrecurring, the approaches discussed in this report emphasize more on the strategies for alleviating recurring congestion. The tools for alleviating non-recurring congestion are also discussed briefly. As seen earlier, the usual causes of freeway congestion can be due to:

- Insufficient capacity at geometric bottlenecks;
- Breakdowns at entrance ramps;
- Insufficient mainline corridor capacity; and
- Regular incident occurrences.

To effectively divide the various measures, based on the type of improvement and geometric conditions along with land development, the strategies could be split into two categories:

a) Managing Existing Supply/Using Existing Capacity more Efficiently; and
b) Increasing Supply/Adding Capacity.
A brief summary of the tools discussed is given in Table 4.1 below. This is based on the type of improvement for each supply measure. Each of these above categories will be discussed with reference to previous implementation and present research.

**Table 4.1: Supply Management Tools**

<table>
<thead>
<tr>
<th>Supply Measure</th>
<th>Type of Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Improvements</td>
<td>• Improved Control Devices</td>
</tr>
<tr>
<td></td>
<td>• Improved Intersections</td>
</tr>
<tr>
<td></td>
<td>• Improved Signals (Computerized)</td>
</tr>
<tr>
<td></td>
<td>• Ramp Metering</td>
</tr>
<tr>
<td>Physical Improvements</td>
<td>• Street Widening</td>
</tr>
<tr>
<td></td>
<td>• Provision of additional lanes without widening the freeway</td>
</tr>
<tr>
<td></td>
<td>• New Highways</td>
</tr>
<tr>
<td>Maximum Utilization of Existing Facilities</td>
<td>• One way Streets</td>
</tr>
<tr>
<td></td>
<td>• Reversible Traffic Lanes</td>
</tr>
<tr>
<td></td>
<td>• Turn Prohibitions</td>
</tr>
<tr>
<td>Arterial Access Management</td>
<td>• Super Street Arterials</td>
</tr>
<tr>
<td></td>
<td>• Arterial Surveillance</td>
</tr>
<tr>
<td>Others</td>
<td>• Motorist Information System</td>
</tr>
<tr>
<td></td>
<td>• Freeway Incident Detection and Management System</td>
</tr>
<tr>
<td></td>
<td>• Exclusive Bus Lanes</td>
</tr>
<tr>
<td></td>
<td>• HOV Lanes</td>
</tr>
<tr>
<td></td>
<td>• Future Technologies</td>
</tr>
</tbody>
</table>
4.1.1 Traffic Improvements

Historically, the engineering profession has assembled information that can be used to guide engineers in the deployment of traffic control devices for use on the highway system. These guidelines have aided the practicing engineer in selecting a particular type of device for a particular application. One such application is improvements to traffic control devices which are still traditionally one of the low cost measures used to alleviate congestion in big cities.

4.1.1.1 Improved Control Devices

Traffic control devices are signs which regulate, warn, and guide traffic on all freeways and arterials. These devices are essential to ensure highway safety and provide orderly and predictable movement of traffic at all times. These devices also include traffic markings and variable message signs. The different types are:

- **Regulatory signs** inform highway users of traffic laws or regulations and indicate the applicability of legal requirements.

- **Warning signs** are used to warn traffic of existing or potentially hazardous conditions on or adjacent to a highway.

- **Guide or information signs** provide directions to motorist services, including route designations, destinations, etc.

- **Variable message signs** inform drivers of conditions of traffic during certain periods of the day. These are either manually changed or controlled automatically and are more applicable along a congested traffic corridor. These are being used extensively now to manage traffic, designate exclusive lanes during construction and maintenance, and also for diversion purposes.
• Traffic markings are lines, object markers, cones or other devices which are attached to the pavement or mounted at the side of the road to guide or warn traffic of obstruction. These also serve as a psychological barrier for opposing streams of traffic, as a warning device for restricted sight and passing devices, etc. Miscellaneous marking lines are used for crosswalks, parking spaces, curbs, etc.

Benefits and Implementation Issues

Improvements in any type of road signing, so as to provide better information to the driver, will be effective in alleviating congestion. Better route markings, street signs, or other devices essential in informing the driver would also help in reducing the level of uncertainty for drivers. Appropriate signs installed to give real-time information could assist in reducing delays, improving roadway control and alleviate congestion. This strategy is very cost effective as it does not involve any type of construction but mainly maintenance of the existing controls and upgrading to attain efficiency. It also establishes separation of traffic through channelization to enhance safety.

To implement the above strategy, the design of the devices should assure proper shape, size, and color in order to draw the attention of the driver. Similarly, placement of the devices should be within the cone of vision of the driver to assist in adequate response time. Operation and maintenance of the devices are also important issues and should be of high standard. Finally, uniformity of the devices also plays an important role in assisting the user in recognition and understanding.

4.1.1.2 Improved Intersections

Intersections are one of the places where improvements could result in subsequent decrease in delays and reduce traffic flow. Intersection traffic control devices such as stop signs, yield signs, and traffic islands can be used to improve the flow of vehicles and assist
in attaining safe passage of pedestrians. Though this may not relieve congestion to a great extent, it has been shown from various case studies that with suitable improvements, some benefits are possible, especially in reducing vehicle delays and stops.

**Benefits and Implementation Issues**

Considering that the costs involved with these improvements are modest, the benefits are substantial. Some important implementation issues to be considered while designing and improving intersections have been established by the Institute of Transportation Engineers (ITE) in order to incorporate these improvements efficiently:

- Coordination of traffic controls used at the intersection with the volume of traffic at the intersection;
- Use of separate right and left turn lanes where traffic flow is heavy;
- Reduction in the area of conflict to employ channelization; and
- The heaviest and fastest flows should be given preference in intersection design to minimize hazard and delay.

**4.1.1.3 Improved Signals (Computerized)**

One of the most common tasks performed by most highway authorities is the optimization of signals. A recent inventory revealed that out of 240,000 urban signalized intersections, 61% needed upgrading of the physical equipment and 12.5% needed signal timing optimization. The introduction of microprocessors has greatly advanced the capabilities of signal control equipment, allowing greater flexibility in signal phasing and timing strategies to better serve traffic. The three main improvements which can be performed on the existing signals are:

- **Regular signal improvements**, such as timing plan strategies or interconnection of signal. These basically involve collection of data of the existing inventory of the signal plans in order to update signal timing for corresponding traffic flows.
• **Computerizing signal systems**, such as coordination of a group of signals or advanced traffic control systems with increased timing flexibility. These involve three elements:
  
a) Coordinating groups of signals by using either interconnection or highly accurate timebased coordinators;
  
b) Systematically optimizing the signal parameters of pretimed signals or the interval settings of traffic actuated signals; and
  
c) Advanced traffic control functions by using master computer controls, which include increased timing plan flexibility, dynamic traffic responsive control features, and on-line traffic performance monitoring and control system components operation.

• **Signal removal and maintenance**: Due to changes in travel patterns, signal removal could provide significant reductions in vehicle delay and in unwarranted stops, provided safety considerations are met with. Similarly, effective maintenance of the systems could also assist in reducing needless delays.

**Benefits and Implementation Issues**

Traffic signal improvements generally provide the greatest payoffs for reducing congestion on surface streets. This strategy can be applied to almost any situation, and the significant benefits and costs involved after implementation of the improvements are shown in the table below. The following tables (Table 4.2 and 4.3) give the travel time savings and annual cost for implementation of the various type of signal improvements.
Table 4.2: Travel Time Savings Resulting From Traffic Signal Improvements

<table>
<thead>
<tr>
<th>Before Condition</th>
<th>After Condition</th>
<th>Percent Improvement in Speed or Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-interconnected Pre-Timed Signals with Old Timing Plans</td>
<td>Advanced Computer Based Control</td>
<td>25%</td>
</tr>
<tr>
<td>Interconnected Pre-Timed Signals with Old Timing Plans</td>
<td>Advanced Computer Based Control</td>
<td>17.5%</td>
</tr>
<tr>
<td>Non-Interconnected Signals with Traffic-Actuated Controllers</td>
<td>Advanced Computer Based Control</td>
<td>16%</td>
</tr>
<tr>
<td>Interconnected Pre-Timed Signals with Actively Managed Timing</td>
<td>Advanced Computer Based Control Plans</td>
<td>8%</td>
</tr>
<tr>
<td>Interconnected Pre-Timed Signals - Various Forms of Master Control and Various Qualities of Timing Plans</td>
<td>Optimization of Signals Timing Plans. No changes in Hardware</td>
<td>12%</td>
</tr>
</tbody>
</table>


Table 4.3: Summary of Annual Costs of Various Traffic Signal Improvements

<table>
<thead>
<tr>
<th>Traffic Control Improvement</th>
<th>Implementation Cost per Signal</th>
<th>Equivalent Capital Outlay</th>
<th>Operations and Maintenance</th>
<th>Total $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimize Previously Interconnected Signals</td>
<td>$2,000-$10,000</td>
<td>$260-$1,300</td>
<td>$500-$1,400</td>
<td>$760-$2,700</td>
</tr>
<tr>
<td>Interconnect and Optimize</td>
<td>$5,000-$13,000</td>
<td>$760-$1,800</td>
<td>$1,100-$2,000</td>
<td>$1,860-$3,800</td>
</tr>
<tr>
<td>Advanced Computer-Based Master Control (Including Optimization and Interconnection)</td>
<td>$3,000</td>
<td>$500</td>
<td>$600</td>
<td>$1,100</td>
</tr>
</tbody>
</table>

Certain issues to consider while implementing the above improvements are:

- It requires very strong traffic engineering expertise, with staff and budgets sufficient to keep up with routine installation and maintenance of the equipment;
- Many local agencies believe that signals operate in a reasonable manner and therefore neglect to devote resources to these needs; and
- Integration of surface street signal with freeway controls to optimize the flow of traffic throughout the entire network shows tremendous promise in alleviating congestion.

4.1.1.4 Ramp Metering

This is thought to be one of the most cost-effective techniques of reducing congestion on the main lines. Using a modified signal placed at the downstream end of the ramp, ramp traffic is released onto the mainline using either a pretimed or traffic responsive cycle designed to respond to the ramp demand and the mainline traffic conditions. Ramp metering is one of the system components of a freeway surveillance and control system. Table 4.4 lists the various ramp metering currently in use for different freeway surveillance and control systems around the United States.

The information about applications of ramp metering in the country is extracted from a list of various freeway surveillance and control system. Table 4.4 presents current use of ramp metering per types of freeway surveillance and control systems. Ramp Metering can be operated in three ways based on the needs of the surveillance and control system. These are Fixed-time or pre-timed, Traffic Responsive, and Integrated or Coordinated.
### Table 4.4 U.S. Freeway Surveillance and Control Systems

<table>
<thead>
<tr>
<th>Type of System</th>
<th>System Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Areawide Systems:</strong></td>
<td></td>
</tr>
<tr>
<td>In Operation</td>
<td>Chicago Metropolitan Area Traffic Systems Center</td>
</tr>
<tr>
<td></td>
<td>Denver Area Ramp Metering Control System</td>
</tr>
<tr>
<td></td>
<td>Detroit SCANDI (Surveillance, Control and Information) System</td>
</tr>
<tr>
<td></td>
<td>Los Angeles Metropolitan Area Management System</td>
</tr>
<tr>
<td></td>
<td>Maryland CHART System</td>
</tr>
<tr>
<td></td>
<td>Minneapolis-St. Paul Twin City Traffic Management System</td>
</tr>
<tr>
<td></td>
<td>San Diego Area Management System</td>
</tr>
<tr>
<td></td>
<td>Seattle FLOW System</td>
</tr>
<tr>
<td>In Planning or Design</td>
<td>Boston Central Artery Third Harbor Tunnel</td>
</tr>
<tr>
<td></td>
<td>Connecticut Statewide Traffic Management</td>
</tr>
<tr>
<td></td>
<td>Fort Worth Traffic Management System</td>
</tr>
<tr>
<td></td>
<td>Phoenix Freeway Management System</td>
</tr>
<tr>
<td></td>
<td>San Francisco Bay Area Traffic Operations Management System</td>
</tr>
<tr>
<td><strong>Corridor Systems:</strong></td>
<td></td>
</tr>
<tr>
<td>In Operation</td>
<td>Convington, KY I-75 Reconstruction projects</td>
</tr>
<tr>
<td></td>
<td>Dallas North Central Express Corridor</td>
</tr>
<tr>
<td></td>
<td>Long Island INFORM (Information for Motorists)</td>
</tr>
<tr>
<td></td>
<td>Virginia I-66/I-395 Traffic Management System</td>
</tr>
<tr>
<td>In Design</td>
<td>Philadelphia I-95 Intermodal Mobility Project</td>
</tr>
<tr>
<td></td>
<td>Santa Monica Freeway SMART Corridor Demonstration</td>
</tr>
<tr>
<td><strong>Mini-Corridor Systems:</strong></td>
<td></td>
</tr>
<tr>
<td>In Operation</td>
<td>New Jersey Turnpike Automatic Traffic Surveillance and Control System</td>
</tr>
<tr>
<td></td>
<td>New York Van Wyck Express Control System</td>
</tr>
<tr>
<td><strong>Linear Systems:</strong></td>
<td></td>
</tr>
<tr>
<td>In Operation</td>
<td>Baltimore Jones Falls Express Surveillance and Control Project</td>
</tr>
<tr>
<td></td>
<td>Cincinnati I-75 Traffic Diversion System</td>
</tr>
<tr>
<td></td>
<td>Seattle FLOW System</td>
</tr>
<tr>
<td></td>
<td>Wisconsin Milwaukee Freeway Control Project</td>
</tr>
<tr>
<td>In Planning or Design</td>
<td>Newark Airport Interchange Surveillance and Control System</td>
</tr>
<tr>
<td></td>
<td>Salt Lake City I-15 Corridor System</td>
</tr>
<tr>
<td><strong>Spot Systems:</strong></td>
<td></td>
</tr>
<tr>
<td>In Operation</td>
<td>Austin I-35 System</td>
</tr>
<tr>
<td></td>
<td>Beaumont Freeway Ramp Closure Gate</td>
</tr>
<tr>
<td></td>
<td>Columbus Ramp Control System</td>
</tr>
<tr>
<td></td>
<td>Portland I-5 and I-84 Ramp Metering Systems</td>
</tr>
<tr>
<td></td>
<td>Philadelphia I-95 Intermodal Mobility Project</td>
</tr>
<tr>
<td></td>
<td>Sacramento Area Ramp Control Systems</td>
</tr>
<tr>
<td></td>
<td>Tucson, AZ Ramp Control Systems</td>
</tr>
</tbody>
</table>

(Source: NCHRP Synthesis of Highway Practice No. 177)
In a fixed-time or pretimed metering system, the ramp signal operates with a constant cycle according to the metering rate prescribed. This rate is fixed based on the average conditions at a given ramp at a given time of the day. The operation is very similar to a fixed-time traffic signal at an intersection. Due to the fixed times, real time information about the mainline conditions are not acted upon in time and cannot respond effectively to the traffic conditions.

Traffic-responsive ramp metering utilizes loop detectors located on the freeway mainlines and on entrance ramps, in addition to either a local or central computer to determine when vehicles are allowed to enter the freeway. Due to its location in the immediate vicinity of the entrance ramp, these obtain real-time information of volume, occupancy, etc. on the upstream and downstream. This approach can be effectively used in conjunction with a HOV bypass lane at an entrance ramp to provide incentive for carpool, vanpool, and bus ridership.

Coordinated or Integrated ramp metering aims at integrating the adjacent traffic control and the ramp metering system. The rates at which the ramps are metered are determined in accordance to the freeway flow and adjacent traffic flow conditions. There are four types of operating strategies recommended for this type of ramp metering:

- **Local coordinated strategy** is used when freeway demands do not require integrated ramp control. The meter rates are selected based on local conditions at each interchange;
- **Area-wide integrated strategy** is a traffic responsive and metering rates are based on corridor flow optimization rather than local conditions at interchanges. This type is very effective in preventing freeway congestion;
- **Diversion strategy** is designed to handle non-recurring type of incidents and metering rates are assigned special timing plans at locations affected by the incident; and
- **Congestion strategy** is applied to manage the spread of congestion if traffic demand exceeds capacity within a critical sub-area of a corridor.

**Benefits and Implementation Issues**

Ramp metering has proven to be very effective in reducing travel time and increasing overall speed and volume on freeways. A survey done by FHWA of seven ramp metering systems in the United States and Canada revealed that average speeds increased by 29% where the systems have been implemented effectively. When delays on ramps are included, average speeds still increased by 20% and travel times decreased by 16.5%. Additional benefits like reductions in accidents from 20 to 58 percent have been achieved. Table 4.5 shows the results on the impacts of the survey mentioned above.

Ideally ramp metering should be implemented as part of an areawide freeway management program. However, if this approach is not feasible and ramp meters are planned for installation at selected individual ramps, careful consideration should be given to their location. For instance, if installed in the vicinity of an already congested arterial, a ramp meter could cause traffic to divert from the freeway to the congested arterial. Ramp Metering may be most-effective in the suburbs, but not so effective within the more densely populated portions of urban areas.
Table 4.5: Ramp Metering Impacts on Average Speeds

<table>
<thead>
<tr>
<th>Location</th>
<th>Length (miles)</th>
<th>Time of Day</th>
<th>Before Ramp Control</th>
<th>After Ramp Control</th>
<th>Percent Improvement</th>
<th>After Including Ramp Delays</th>
<th>Percent Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minneapolis, I-35 W (44)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>16.6</td>
<td>7:15-8:15 am</td>
<td>33.8</td>
<td>45.5</td>
<td>34</td>
<td>43.0</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6:30-9:00 am</td>
<td>43.9</td>
<td>50.1</td>
<td>14</td>
<td>48.5</td>
<td>10</td>
</tr>
<tr>
<td>Outbound</td>
<td>12.7</td>
<td>4:30-5:30 pm</td>
<td>33.7</td>
<td>40.1</td>
<td>19</td>
<td>38.6</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3:30-6:30 pm</td>
<td>38.5</td>
<td>45.7</td>
<td>19</td>
<td>44.4</td>
<td>15</td>
</tr>
<tr>
<td>Chicago, Eisenhower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expressway (45)</td>
<td></td>
<td>2Hr: AM Peak</td>
<td>30.3</td>
<td>33.0</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>9.4</td>
<td>4Hr: AM Peak</td>
<td>37.7</td>
<td>39.7</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los Angeles, Santa Monica Freeway (46)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>13.5</td>
<td>6:30-9:30 am</td>
<td>36.2</td>
<td>50.6</td>
<td>40</td>
<td>41.4</td>
<td>14</td>
</tr>
<tr>
<td>Houston, Gulf Freeway (47)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>6</td>
<td>7:00-8:00 am</td>
<td>20.4</td>
<td>32.6</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los Angeles, Harbor Freeway (48)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outbound</td>
<td>4</td>
<td>3:45-6:15 pm</td>
<td>25.9</td>
<td>40.3</td>
<td>55</td>
<td>37.4</td>
<td>44</td>
</tr>
<tr>
<td>Detroit Lodge Freeway (49)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>6</td>
<td>2:30-6:30 pm</td>
<td>27.3</td>
<td>36.4</td>
<td>33</td>
<td>32.6</td>
<td>19</td>
</tr>
<tr>
<td>Toronto, Queen Elizabeth way (50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inbound</td>
<td>3.9</td>
<td>7:00-9:00 am (Good Cond.)</td>
<td>21.1</td>
<td>30.9</td>
<td>45</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7:00-9:00 am (Poor Cond.)</td>
<td>13.4</td>
<td>21.4</td>
<td>59</td>
<td>16.7</td>
<td>24</td>
</tr>
<tr>
<td>Average, All Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average, Including Ramp Delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1.2 Physical Improvements

Apart from the regular traffic improvements, other strategies could be applied based on availability of land, existing conditions, and the environment. Such improvements are applied to the roadway directly to effectively increase capacity. The three main tools discussed under this are street widening, provision of additional lanes, and construction of new highways.

4.1.2.1 Street Widening

As mentioned earlier, this tool is a method of increasing capacity and essentially falls under a reconstruction project. Careful consideration and planning is thus required in its implementation. Widening can be essentially done for 10 to 15% of the total urban freeway mileage. It results in the addition of needed freeway lanes along any requisite geometric and structural changes at ramps, bridges, and interchanges.

Benefits and Implementation Issues

Increase in lane width produces a direct increase in traffic flow and similarly lesser width reduces the traffic and produces more queues leading to increase in congestion. It is important to realize that during peak periods the effect of greater width is not very significant, so care should be taken that this strategy is applied to areas like intersections and ramps to assist in removing the bottlenecks in the highway system.

Table 4.6 shows significant increase in capacities for urban four-lane and urban six-lane freeway volumes. The increase in the number of lanes from four to six, due to widening subsequently shows increase in the capacity to handle more traffic.
Table 4.6: Maximum Observed One-Way Hourly Freeway Volumes

<table>
<thead>
<tr>
<th>URBAN FOUR LANE Location</th>
<th>Total Volume</th>
<th>Average Volume Per Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-35 W, Minneapolis, MN</td>
<td>4690</td>
<td>2345</td>
</tr>
<tr>
<td>I-64, Charleston, WVA</td>
<td>4152</td>
<td>2077</td>
</tr>
<tr>
<td>I-71, Kansas City, MO</td>
<td>5256</td>
<td>2628</td>
</tr>
<tr>
<td>I-59, Birmingham, AL</td>
<td>4802</td>
<td>2401</td>
</tr>
<tr>
<td>I-295, Washington, D.C</td>
<td>4480</td>
<td>2240</td>
</tr>
<tr>
<td>I-45, Houston, TX</td>
<td>4240</td>
<td>2120</td>
</tr>
<tr>
<td>I-55 Jackson, MS</td>
<td>3733</td>
<td>1867</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>URBAN SIX-LANE Location</th>
<th>Total Volume</th>
<th>Average Volume Per Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-40, Nashville, TN</td>
<td>6104</td>
<td>2035</td>
</tr>
<tr>
<td>I-25, Denver, CO</td>
<td>6477</td>
<td>2159</td>
</tr>
<tr>
<td>I-495, Prince George County, MD</td>
<td>6993</td>
<td>2331</td>
</tr>
<tr>
<td>I-5, Portland, OR</td>
<td>6474</td>
<td>2158</td>
</tr>
<tr>
<td>I-15, Salt Lake City, UT</td>
<td>6357</td>
<td>2119</td>
</tr>
<tr>
<td>I-35W, Minneapolis, MN</td>
<td>6909</td>
<td>2303</td>
</tr>
<tr>
<td>I-390, Hillside, IL</td>
<td>6149</td>
<td>2047</td>
</tr>
</tbody>
</table>

(Source: Transportation Research Board, Highway Capacity Manual, 1985.)

This tool may not be applicable to most urban places due to the scarcity of land. The costs associated with such widening vary according to the amount of land required and the extent to which other improvements such as signalization are incorporated into the project.

4.1.2.2 Provision of Additional Lanes Without Widening the Freeway

When the alternative of adding lanes with construction is not feasible, a low-cost geometric modification can be used to reduce freeway congestion on a temporary basis. This can be achieved in two ways:

- Using one or more shoulders as travel lanes (usually done during peak hours and in the peak direction); and
- Reduce lane widths to provide additional lanes (done in the existing pavement).

A recent survey of highway agencies about the type of modifications applied revealed that:
- More than 96% of all agencies in the survey used improvement strategies that did not involve changing of the width of the lanes; and
- 70% of the highway agencies used narrower lanes in order to provide additional lanes.

**Benefits and Implementation Issues**

Though this is a temporary measure, a FHWA study found that for 1984, in 37 cities with populations over 1 million, almost 32% of the urban freeway mileage could reduce congestion through such low-cost measures. The costs involved vary according to the circumstances and the condition of the existing freeway, but, in general, costs per mile are $1.3 million for construction and engineering and $12,000 per year for maintenance. Overall, these measures have the potential of returning a B/C ratio of 7:1.

Some implementation issues to consider during the planning and design of these improvements involve proper cooperation and coordination between the state highway agencies and traffic enforcement officials. Additional warning signs to alert drivers to the conditions and advanced information and education to describe the program are also essential.

**4.1.2.3 New Highways**

One of the most traditional ways of increasing capacity is building new highways. This measure will have to be taken if other TSM measures cannot add more capacity provided that circumstances allow it. The increasing suburbanization of urban America is revealing significant capacity deficiencies in the highway network within the suburbs. But as the interstate highway program draws to a close, the emphasis on highway construction in this...
country has clearly shifted to the reconstruction and rehabilitation of the existing system. Between 1983 and 1985, the number of miles of highways and bridges resurfaced, restored, rehabilitated, or reconstructed was 15 times greater than the number of new miles constructed. This decline is mainly attributed to the reduced amount of funds which have been allocated for new construction projects.

Though highway agencies see more short-term improvements to be effective, some transportation departments are looking at highway construction as a means of accommodating the rising growth in the cities. For example, in the Maricopa County of Phoenix, Arizona, the Arizona DOT has set into motion a $5.8 billion highway program to add 233 miles to the urban freeway system. More examples of new highways are discussed in the next chapter.

Benefits and Implementation Issues
By attracting vehicles that currently use the existing road system, a new highway can substantially reduce congestion in the corridor. Adding new capacity can also provide access to lands on the urban fringe and open up new industrial and commercial sites for development in addition to reducing congestion. The magnitude of this impact depends on creation factors such as funds, construction time, and also whether new construction would eventually lead to a new source of congestion. Although this tool is not always effective, some additional benefits apart from additional capacity are possible with new construction, like decrease in accidents, improved air quality, and new developments.

Certain implementation issues to consider while applying this measure are:
- Initial investment costs are very high and thus financing the new highway will be a key issue; and
- Achieving a consensus that new construction is the appropriate course of action and a review of the possible long term and short term impacts have been evaluated.
4.1.3 Maximum Utilization of Existing Facilities

Earlier we discussed how physical improvements to the existing freeway with additional lanes and capacity could alleviate congestion. But circumstances and the land conditions do not always let you perform certain measures as they are not feasible. In such cases, the alternative supply measure which can effectively utilize the available highway system to achieve subsequent reductions in congestion, could be applied. The three main tools under this are One Way Streets, Turn Prohibitions, and Reversible Traffic Lanes.

These three strategies are also referred to as large capacity alternatives and expected benefits from application of these measures in terms of capacity increase, travel time savings and accident reduction is given in Table 4.7.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Range of Capacity Increase Reported</th>
<th>Range of Reduction Travel Time Reported</th>
<th>Range of Accident Reduction Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-Way Operation</td>
<td>20-50%</td>
<td>20-40%</td>
<td>0-60%</td>
</tr>
<tr>
<td>Reversible Flow</td>
<td>20-50%</td>
<td>10-25%</td>
<td>0-30%</td>
</tr>
<tr>
<td>Left Turn Prohibition</td>
<td>14-40%</td>
<td>35-100%</td>
<td>40-70%</td>
</tr>
</tbody>
</table>

(Source: Alternatives for Improving Urban Transportation, USDOT, 1978)
4.1.3.1 One Way Streets

Most streets are traditionally designed for two-way traffic, which are nowadays eventually used as one-way to accommodate the high volume of traffic. These can be operated either on a temporary or permanent basis. They be operated as:

- A street on which traffic moves in one direction all the time;
- A street which is normally one way but at certain times may be operated in the reverse direction to provide additional capacity in the predominant direction of flow; and
- A regular two-way street which can be designated as one-way during morning and evening peak periods.

Benefits and Implementation Issues

One-way streets provide additional capacity to satisfy peak period traffic demands without large capital expenditures. Most cities are faced with a peak rush hour and need to be relieved of the long queues at this time. The cost of construction for one-way streets is approximately $27,000/mile. This depends on the urban area setting and environment. Benefits include:

- Reducing intersection delays caused by vehicle turning movement conflicts;
- Implementing a city-wide system of one-way streets can increase overall network capacity from 20 to 50%;
- Reduction in travel time from 20 to 40%;
- Additional benefits are reduction in accidents up to nearly 60% due to lesser conflicts;
- Redistribution of traffic to adjacent streets and simplification of signal timing by reducing multiphase signal improvements can also be achieved; and
- Meet changing traffic patterns almost immediately and at negligible cost.

During implementation it is important to account for the fact that existing two-way streets should be altered to one-way streets only if it can be shown that a specific traffic problem
will be alleviated or the overall efficiency of the transportation system will be improved. It is also essential to take into account if parallel streets of suitable capacity, preferably not more than a block apart, are available or can be constructed. And finally, public outreach is needed before actual construction of the street is begun.

4.1.3.2 Reversible Traffic Lanes

Many urban arterials have strong directional flows during the morning and evening peak periods. Reversible lanes can be used to increase operational efficiency of such arterials by carrying traffic in different directions at different times of the day. Earlier reversible lanes carried traffic in one direction during the morning peak hour and in the opposite direction during the evening peak hour. More recently, some highway agencies have begun to use the reversible lanes as two-way left turn lanes (TWLTL) during the off-peak period. One of the outstanding examples of multiple reversible lanes presently in use, is the eight-lane Outer Drive in Chicago, which operates a 6-2 lane split during peak-hour rush. Results obtained have proven to be very effective by providing extra lanes for use by the dominant direction of flow.

Benefits and Implementation Issues

This is one of the most efficient low-cost modifications applicable for increasing rush-period capacity of existing streets. It effectively makes use of all the lanes and is attained with minimal capital costs. Additional benefits include decrease in travel times by 10 to 25% and capacity increases of 20 to 50%.

Several factors have to be considered in order to justify the use of a reversible traffic lane as this is a very short term approach and should not prove to be a detriment to decreasing congestion. These issues are:
Evidence of Congestion: If the level of service during certain periods decreases to a point that it is evident that traffic demand is in excess of actual capacity, the possibility of reversible lanes should be considered.

Time of Congestion: Reversible lanes should be used when congestion occurrence is periodic and predictable.

Availability of Capacity at Access Points: Care should be taken that there is adequate capacity at the end points of the reversible lane system, allowing an easy transition of vehicles between the normal and reversed lane conditions.

4.1.3.3 Turn Prohibitions

When conflicts occur between turning vehicles and pedestrians with other vehicles, congestion delay and safety problems are caused. It is during such situations that this particular supply tool becomes very handy. Prohibiting turns can be an effective way to eliminate conflicts and reduce delays.

It is not always necessary to prohibit turns in order to alleviate congestion. Turning movements should be prohibited only during those hours when study data indicates that a suitable alternative route is available and congestion is reduced. Another alternative to restricting turns is the designation of a left turn lane for storage or the technique of introducing continuous left turn lanes.

Benefits and Implementation Issues
Overall capacity increases of 14 to 40%, accident reductions of 40 to 70%, and travel time reductions of 35 to 100% have been reported in places where left turn prohibitions have been instituted. All around the country, reductions in accidents were reported due to the application of prohibiting turns. San Francisco indicated that accidents at four intersections were reduced by 38% to 52%, and a study in Wichita, Kansas reported that
accidents were reduced at some intersections from 43% to 69% due to prohibition of turns.

As stated earlier, turns should be prohibited only if a proper evaluation has been performed to examine the following specifications. This evaluation included:

- The amount of congestion and delay caused by turning movements;
- The availability of suitable alternative travel paths if turns are restricted; and
- The possible impact of traffic diversion on congestion and accidents at intersections that would be required to accommodate the traffic diverted by the turning restriction.
- The feasibility of alternative solutions, such as provision of separate storage lanes for turning movements.

4.1.4 Arterial Access Management

Freeways in urban areas routinely experience significant traffic congestion during several peak demand hours. Diversion of short trips from freeways to arterials would help solve the problem without construction of new lanes. In 1987, approximately 30% of all the annual vehicle miles were on arterials and local streets. Any improvements made on these facilities will also considerably decrease congestion, pollution, and energy use. The two various strategies that will be discussed under this are the construction of super street arterials and surveillance and control systems.
4.1.4.1 Super Street Arterials

This is a relatively new approach and has not been implemented yet, though some states have made simulation studies to predict the results and implementation issues. As discussed earlier, if we have to do away with any additional construction of new freeway lanes, diversion could be an effective alternative. However, such diversion will occur only if the traffic speed and capacity of selected urban arterial streets can be improved significantly. The regional arterial, or super street, is proposed as a class of facility that would have the continuity, speed, and capacity characteristics to attract short and medium length trips. The design and operational guidelines for these arterials have been developed based on extensive research. These involve:

Continuity: Regional arterials streets and networks should provide sufficient continuity to attract travelers making trips of a length at least equivalent to the average areawide trip length.

Signal Timing Policy: The capacity of any approach to a signalized intersection primarily depends on the percentage of the available green time provided to that approach or the effective green time to cycle (g/C) length ratio. If a regional arterial is to carry large volumes of traffic over long continuous street sections, the g/C ratios for all intersection approaches must be appropriately established by operating policy. A policy of providing 70% of the available intersection green time to movements on the regional arterial is considered the desirable minimum.

Geometric Design Standards: The geometric standards for these arterials should be appropriate for high-volume and relatively high speed facilities. Minimum design speeds of 40 to 50 mph should be adopted and strictly maintained. Grade separation structures should be provided for all existing at-grade railroad crossings.

Mass Transit Operations: The high operating speeds and continuity of regional arterials make them ideal for public transportation routes. Care should be taken that all public
transportation passenger boarding and debarring operations should be performed while buses are in appropriately designed bus turnoffs.

Access Control Standards: Primary control of turn movements is a primary element of the regional arterials. Median barriers are an excellent means of controlling left turns from the arterial and allowing them only at carefully selected locations. Additionally, right turns from the arterial should be separated from through traffic.

Right-of-Way for Undeveloped Areas: Most of the regional arterial streets that are developed in the near future will be in developed areas where right-of-way (ROW) is probably scarce and new acquisitions are very expensive economically, socially, and environmentally. However, where regional arterials are designed for extensions into undeveloped areas, ROW specifications should be developed around desirable standards.

Intersection Grade Separations: Grade separations should be considered only where the crossing traffic volumes are large enough that a critical user delay problem exists and cannot be solved by any less expensive measure.

Benefits and Implementation Issues
The various benefits attained by implementing this measure could be:

- Even if the estimated costs of the regional arterial are less than half the cost of new freeways, they would provide half to two-thirds the traffic productivity of the freeway having the same number of lanes;
- The right of way requirements for new alignments would be less than those of a freeway with the same number of lanes;
- Most regional arterials would be upgraded versions of existing arterials and might require little construction;
- The total cost of new arterials is approximately $1.5 million per-lane-mile while that of new freeways is $4.5 million per-lane-mile;
- The B/C ratios fall between 2:1 to 4:1;
• A primary benefit of constructing a new arterial would be reduced traffic congestion on adjacent roadways due to increased capacity, and the secondary benefit would be decreased accident rates along with diversion of through traffic;

• From the research conducted and the simulations performed, it has been realized that super street arterials could provide a 15% increase in vehicular capacity and 20% decrease in accidents; and

• By converting a typical suburban arterial with signalized intersections to a super street, capacity increases of about 50 to 70% is possible.

Based on the research conducted, implementation issues which were deemed important can be briefly discussed as stated below:

• It should be clearly established that the construction of these new roadways does not mean more congestion on them;

• Construction of the new arterial would require time and design; operational guidelines should be carefully followed in order to avoid any discrepancies at a later stage; and

• A highly disciplined operating policy that guarantees maintenance of all the features is essential.

4.1.4.2 Arterial Surveillance and Management

Arterial surveillance is established by surveillance, communication, and control (SC&C) systems. The objective of these systems is to reduce the detrimental impacts of non-recurring congestion. It is a known fact that 60% of the congestion is non-recurring caused by incidents and delays. These systems primarily consist of four main components:

1) A surveillance system to monitor the traffic operations on the freeways/arterials and identify where the problem occurs;

2) Ramp meters to control the number of vehicles entering the freeway/arterial;
3) An incident management program to quickly and effectively respond to, manage the impacts of, and clear major and minor incidents; and
4) An information system to notify motorists of the location and approximate duration of traffic delays and alternate routes to avoid traffic delays.

The above four components can be applied as separate supply measures to reduce congestion as we had discussed ramp metering techniques earlier. The elements that compose the above four components include:

- A system of electronic loop detectors
- Closed circuit televisions
- Call boxes
- Courtesy patrol units
- Highway Advisory Radio (HAR)
- Ramp metering equipment
- An incident management team
- Accident investigation sites
- Changeable message signs/lane use signals
- Centrally located computer center

**Benefits and Implementation Issues**

One key benefit with these systems is the reduction in the duration of congestion due to incidents. Increases in vehicular capacity of 30% have been achieved with the implementation of these systems. The cost of surveillance communication & control systems are approximately $1 million per lane mile to implement and $100,000 per year/corridor to maintain and operate. If the SC&C systems are installed with the conjunction of freeway reconstruction and expansion projects, then the cost reduces by $0.5 million per lane mile. B/C ratios of 12:1 are expected to be produced.
Implementation issues to consider are:

- Key issues involved in the implementation of these systems are funding and coordination. Although these systems are expensive to implement on an areawide basis, the benefits far outweigh the cost. Coordination is very essential for the effective implementation of these systems.

- Due to the fact that 60% of the congestion is due to incidents, a surveillance and control system would be necessary, otherwise only half of the congestion reduction would be attained.

4.1.5 Exclusive Bus Lanes

One supply management measure which has been applied to many cities to encourage transit use is exclusive bus lanes, where automobiles and other non-bus traffic are banned. Exclusive bus lanes are intended to free buses from traffic congestion and give them a travel time advantage over private vehicles. Buses are more efficient users of road space than private cars. A bus can carry up to 30 times as many passengers as a car, but it only contributes three times as much to congestion. By eliminating delays to buses caused by other traffic, a net economic benefit can result. One method of doing this is to give buses priority over all other vehicles. This can be done by allocating them special facilities. This strategy is more effective in developing countries where the percentage use of transit is greater. The different types of bus lanes are:

- **With-flow bus lanes:** These lanes are reserved for buses traveling in the same direction as the general traffic;

- **Contra-flow bus lanes:** These lanes are reserved in a one-way street for buses traveling in the opposite direction of the general traffic;

- **Reserved bus lanes on freeways:** These can be reversible for peak hour traffic flow. These give priority access to freeways and other facilities;
• **Bus only street**: Only buses are allowed to travel on the street; and

• **Busways**: These are segregated roads for buses only. They are usually set up for a certain route pattern.

With-flow bus lanes are used commonly to provide buses the exclusive use of the nearside lane. Occasionally, median lanes are used for this purpose. One problem encountered with these lanes is the occurrence of congestion before a signalized intersection. Research in the United Kingdom has shown that the capacity of the intersection can be maintained by stopping the bus lane 50 to 80 meters short of the stop line of the intersection. This area is called the 'setback', and can be used by other vehicles.

Contra-flow bus lanes allow buses to travel in the opposite direction of normal traffic. These are often used in new one-way street systems to maintain existing routes. The major difference between the two types of lanes lies in the type of enforcement. Contra-flow lanes are, for the most part, self enforcing. The cost to implement a contra-flow lane is usually higher than a with flow lane because of complications at beginning and end junctions, the need for some separation between lanes, and extra signalization at pedestrian crossing.

**Benefits and Implementation Issues**

The advantages of dedicated bus/transit lanes is that more people are moved while decreasing the volume of vehicles on the road. This decrease in traffic increases the speed at which vehicles travel and thus reduces travel time and exhaust emissions. Another benefit is that buses are the most flexible form of mass transit. They can be re-routed or re-scheduled quickly to accommodate rider demand. This strategy serves in decreasing travel time of transit, thereby making it more attractive and convenient for users. This in turn causes more commuters to shift to transit, decreasing the number of vehicles on the road. If new construction is required, the costs to set up exclusive bus lanes is approximately $1.5 million dollars per mile.
There are five criteria associated with implementing a bus lane:

- A review of the characteristics of the area to evaluate travel, employment, population, and socio-economic factors should be established. This would include identifying major trip origins and destinations in the corridor, local store owners and residents views, as well as vehicle occupancy;
- Based on the information obtained in step one, access routes must be defined. This includes examining logical pick-up and drop-off points, and specific market areas for the service. The bus routes that will be developed should be designed to serve these markets;
- The transit support facilities should be designed to serve the identified market areas and to minimize illogical movements. These include park-and-ride lots and transit centers;
- A more detailed plan needs to be prepared to outline routes and schedules for the bus service. It is important to provide at least a minimum level of service during the mid-day and evening. People surveyed often cite the lack of such a service as a deterrent to their use of the bus; and
- The final step is to consider is the integration into the HOV system. For bus service using HOV to be successful several components need to be included. They are cross-town and neighborhood feeder routes, transit hubs and other support elements. This is used to make the system broader and more accessible to the public.

4.1.6 High Occupancy Vehicle (HOV) Facilities

New approaches for maintaining urban mobility are being investigated continuously, and HOV lanes is one among them. This concept involves reserving multiperson lanes and emphasizes person movement rather than vehicle movement. HOV lanes and bypass treatments are relatively quick to implement and inexpensive to construct. When operated at suitable levels of service, they save peak-period travel time besides carrying more
people. HOV lanes do not exactly fit into a typical transportation demand strategy or a supply management strategy, but are actually a careful mix of demand principles applied into the existing infrastructure.

Priority treatments for high-occupancy vehicles are generally intended to help maximize the ability to move people along a roadway by altering the manner in which the roadway is designed or operated. This is done to provide HOV's (carpools, vanpools, and buses) with:

(a) Travel Time Savings: The segregation of HOV from mixed-flow traffic can ensure HOV-lane travel speeds approaching the speed limit. Thus, during congestion, those riders who are willing to share a ride or take transit can realize a significant reduction in overall travel time.

(b) Trip Time Reliability: In many urban areas it is estimated that accidents or other non-recurring accidents are responsible for roughly 50% of the delays caused on the freeways. By using HOV lanes these situations will be reduced, and motorists will have reliable trip times.

The objectives of HOV priority treatments are:

- To include mode shift;
- Increase person carrying capacity of highway corridors;
- Reduce total travel time;
- Reduce or defer the need to increase highway vehicle-carrying capacity;
- Improve efficiency and economy of public transit operations; and
- Reduce fuel consumption.

There are six types of HOV facilities, five of which are applied as line-haul treatments and the sixth provides bypass opportunities at isolated traffic bottlenecks. These six types are:
Busway HOV Facility, Separate Right-of-Way: A roadway or lane/lanes developed in a separate right-of-way and designated for the exclusive use of high-occupancy vehicles. This is commonly used by buses.

Barrier-separated HOV Facility, Freeway Right-of-Way: A roadway or lane(s) built within the right-of-way that is physically separated by barriers or pylons from other freeway lanes and is designated for the exclusive use of high-occupancy vehicles during certain portions of the day.

Buffer-separated HOV Facility, Freeway Right-of-Way: A non-physically separated lane(s) containing a buffer that is oriented in the same direction as adjacent mixed-flow lanes. This facility is commonly the inside lane of the freeway cross-section, adjacent the median barrier. This is also termed as concurrent flow lanes.

Nonseparated HOV Facility, Freeway Right-of-Way: A designated lane containing no buffer separation with adjacent freeway lanes and oriented to operate in the same direction as the adjacent mixed-flow lanes.

Contraflow HOV Facility, Freeway Right-of-Way: A designated freeway lane or lanes (commonly the inside lane) in the off-peak direction of mixed flow travel. This is designated for the exclusive use by high-occupancy vehicles traveling in the peak direction during peak commuting periods. The lane is usually separated from the off-peak direction travel lanes by insertable plastic posts or movable barriers.

Queue Bypass HOV Facility: A short, often nonseparated lane, designed to operate in the same direction as the adjacent mixed-flow traffic lanes through an isolated traffic bottleneck, a toll plaza, or a metered location.

Each of the above HOV facility types comprises a number of supporting improvements and transportation demand programs to make the facility definition valid. The current statistics indicate that number of HOV miles till 1993 is 540 miles (Ref. Table 4.8).
Table 4.8: Characteristics of Existing Freeway/Expressway HOV Facilities

<table>
<thead>
<tr>
<th>Total Miles of HOV Facilities</th>
<th>540</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Miles of HOV Facility</td>
<td>8</td>
</tr>
<tr>
<td>Types of HOV Facilities:</td>
<td></td>
</tr>
<tr>
<td>• Busways</td>
<td>8%</td>
</tr>
<tr>
<td>• Barrier Separated Two-Way</td>
<td>3%</td>
</tr>
<tr>
<td>• Barrier Separated Reversible Flow</td>
<td>15%</td>
</tr>
<tr>
<td>• Concurrent Flow, Buffer Separated/Non Separated</td>
<td>63%</td>
</tr>
<tr>
<td>• Contraflow</td>
<td>11%</td>
</tr>
<tr>
<td>Occupancy Requirements:</td>
<td></td>
</tr>
<tr>
<td>• Buses and/or vanpools, taxis</td>
<td>19%</td>
</tr>
<tr>
<td>• 3 + HOV Facilities</td>
<td>9%</td>
</tr>
<tr>
<td>• 2 + HOV Facilities</td>
<td>72%</td>
</tr>
</tbody>
</table>

(Source: The Urban Transportation Monitor, November, 1993)

Development of HOV Facilities

The first major HOV project in the United States was implemented in 1969 on the Shirley Highway in Northern Virginia. Since then, numerous areas have developed priority measures for HOV's. Currently there are a total of 40 projects in 20 metropolitan area in operation in North America. The steady growth in the number of miles of HOV lanes is clearly shown in the figure below. The number of miles is projected to increase to 850 miles due to the addition of new projects. This represents an increase of 150% if all the projects are implemented in that time frame.

HOV activities have been in operation in other countries like Australia, Germany, England, Turkey, and Spain. The HOV facilities in operation worldwide were planned and designed to address similar types of concerns and problems as those faced in the United States, only with the exception that in the United States carpools and vanpools are allowed to use the HOV lanes, while in other countries these are used primarily for buses.
Benefits and Implementation Issues

The primary purpose of HOV facilities is to increase the people-moving (versus vehicle-moving) capacity of a highway. The results due to implementation of various HOV projects are clearly shown in Table 4.9 below.

Table 4.9: Impact of HOV Facilities on Person Movement and Vehicle Occupancy

<table>
<thead>
<tr>
<th>Facility</th>
<th>HOV FACILITIES</th>
<th>GENERAL PURPOSE LANEs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Buses</td>
<td>Cars/Vans</td>
</tr>
<tr>
<td>Störley Highway (No.Virginia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0630-0930</td>
<td>506</td>
<td>4128</td>
</tr>
<tr>
<td>0700-0800</td>
<td>191</td>
<td>2273</td>
</tr>
<tr>
<td>I-495 Contraflow Lane (N.Y.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0700-0930</td>
<td>1600</td>
<td>-</td>
</tr>
<tr>
<td>0730-0830</td>
<td>650</td>
<td>-</td>
</tr>
<tr>
<td>Oakland Bay Bridge (CA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600-0900</td>
<td>367</td>
<td>4183</td>
</tr>
<tr>
<td>I-5: FLOW System (Seattle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0645-0745</td>
<td>425</td>
<td>(all veh.)</td>
</tr>
<tr>
<td>1645-1745</td>
<td>380</td>
<td>(all veh)</td>
</tr>
</tbody>
</table>

(Source: A Toolbox for Alleviating Traffic Congestion, ITE, 1989)

High-occupancy vehicle facilities have been planned, designed, and constructed in a 3-to-8 year time frame. The construction involves well-known highway technology. Some additional benefits are:

- A 5% to 20% increase in peak hour/lane efficiency for the total highway facility can be expected to result from an HOV project.
- Concurrent flow HOV lanes can reduce peak-period vehicle trips by 2% to 10%.
• Barrier separated HOV lanes can reduce peak-period vehicle trips by as much as 30%.
• An average freeway lane carries about 2100 people/hour during peak period, while one of the most successful HOV facilities, located in Washington, DC carries over 15,000 persons per hour.

As expected, the costs of a HOV facility vary greatly depending upon the type of facility. Reserved lanes may cost a few thousand dollars per lane for signings and markings, while separate facilities may cost up to $5 million per-lane mile, similar to the costs for lane widening projects. Specific costs on various types of HOV facilities are:
• Barrier separated HOV lanes cost $4 to $10 million per lane mile to construct;
• Concurrent and contraflow HOV lanes cost $0.5 to $2 million per lane mile to construct;
• Arterial HOV lanes cost $0.5 to $2 million per lane mile to construct; and
• One HOV facility in California was implemented for less than $40,000 per mile.

For effective implementation of these facilities, certain guidelines have been established. These are stated briefly below.

**Congestion**

The purpose of using HOV facilities is to provide more efficient travel than would be possible in mixed-flow while encouraging mode shifts to high occupancy vehicles. This can only happen with the existence of severe, recurrent traffic congestion. Without existing or forecasting congestion, the HOV alternative offers no substantial benefits for single-occupant drivers to switch to carpool, vanpool, or bus. Although the definition of congestion varies from place to place, a good measure of congestion is when average freeway speeds are 30 mph or less during the peak hour, or 35 mph or less during the peak period. In some instances, an HOV alternative has been considered for a congested freeway that could operate relatively smoothly with an added mixed-flow lane, but for
which future congestion is predicted. This constitutes an attempt to take a longer term mitigation action for an inevitable problem.

Travel Time Saving

Travel time saving has become one of the most reliable predictors of HOV viability, and it must exist to encourage shift. For long distance treatments, a five minute or more savings per trip is generally recognized as a prerequisite. This threshold, based on before and after experiences from various projects, does weigh impacts of transfer time that may be associated with changing modes at either end of the trip. Time savings of less than five minutes may still justify consideration of queue bypass or arterial HOV treatments, where a modest investment benefits many drivers.

Person Throughput

The number of persons projected to use the HOV lane should exceed the average number of persons carried in an adjacent or comparable mixed-flow lane. Initially, the number of projected users may not achieve this, and some time may be required for an HOV market to be created. A policy memorandum in one FHWA division office in California recommended that an HOV lane be considered when the forecast person movement on the HOV lane is equivalent to or in excess of a comparable mixed-flow lane within five years following implementation. Whatever time period is adopted, there should be a reasonable expectation that an HOV lane will move more persons in peak demand periods.

Vehicle Throughput

To maintain public respect for and acceptance of the HOV lane, vehicle volumes should meet some minimum expectation. Experience suggests that this threshold varies by treatment and locale. In the Seattle area, dedicated HOV lanes are expected to carry about 400 to 450 vehicles per hour to look adequately used, while in southern California, the threshold is a minimum of 750 to 800 vehicle per hour. Local perspective is needed to define what would constitute an acceptable level of use. Few long distance HOV lanes operate with less than 400 peak hour vehicles.
Local Agency and Public Support

HOV treatments need support by local, regional, and state agencies, preferably as part of a larger transportation demand or congestion management program. Commitments and responsibilities are sometimes shared, where appropriate, by local and state transportation agencies. Public support is enhanced through communication strategies. Education, marketing, and public involvement activities during planning, implementation, and subsequent operation are tools in obtain and maintaining a broad based constituency. Public communication strategies can be promoted through public awareness programs to disseminate information on the consequences and benefits of the HOV project, advertising, rideshare matching, and employer outreach services to promote concepts such as parking for carpools and vanpools.

Enforceability

Enforcement is needed for any HOV treatment, even those that are adequately used and rely on a minimum of operational support. Early involvement during the planning and design process by enforcement agencies in identifying strategies and complimentary sites to facilitate enforcement can be critical. State and city traffic regulations may have to be revised for enforcement applicability, and this is best accomplished during planning activities.

4.1.7 Freeway Incident Detection and Management Systems

4.1.7.1 Freeway Incident Detection

"Incident management is the systematic, planned and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents, and mobility of the highway; by systematically reducing the time to detect and verify an incident occurrence, implement the appropriate response, and clear the incident, while managing the affected flow until full capacity is recovered," (McDade 1992).
A 1986 FHWA staff study concluded that non recurring congestion accounts for as much as 60% of all urban freeway congestion. However, efforts to reduce nonrecurring congestion have not received much attention in the past. One major problem with incidents is that it is virtually impossible to predict just where, when, and what kind of incident might occur. Another problem with incidents is their cumulative effect over time. Of the incidents that are reported by police and highway departments, the vast majority, nearly 80 percent, are vehicle disablements- cars and trucks that have a flat tire or run out of gas, (Grenzeback 1992). Out of these incidents, 80 percent end up on the shoulders of the highway for an average of 15 to 30 minutes. During off-peak hours, when traffic volumes are low, the disabled vehicles have minimal impact on the traffic flow. However, when traffic volumes are high, the presence of a stalled vehicle or a motorist performing maintenance on his or her automobile in the break down lane can slow traffic in the adjacent lane, causing 100-200 motor vehicle hours of delay to other motorists.

4.7.1.2 Incident Congestion Management

The critical aspect for incident management is rapid restoration of normal highway operations, therefore early detection and rapid response to incidents is required. Incident congestion can be reduced by clearing incidents as quickly as possible and diverting traffic before vehicles back-up around the incident. According to Grenzeback, the time saved an incident management program depends on how well the four stages of an incident- detection, response, clearance, and recovery are managed, and these are explained briefly below.

Detection
The concern about incident detection is related primarily to minor incidents. Minor incidents may go unreported for 30 minutes or more, while major incidents usually achieve response
between 5-15 minutes. This discrepancy between major and minor incidents response time is
due to citizens reporting only major incidents and letting minor incidents pass. A significant
accident may trigger up to a dozen calls to the police.

Automatic vehicle detectors, usually wire-loop detectors imbedded in the pavement, are used in
about six cities to monitor traffic flow and detect the effects of incidents. Closed-circuit
television cameras are also used to monitor bridges, tunnels, and a few highly congested
highway corridors. Other means of incident detection include the use of CB radios that are
equipped in public agency vehicles and the use of cellular phones to pin point incidents.

Response
It is the responsibility of the police to handle and identify incidents to access what help is
needed at the scene. Dispatchers usually handle the information from the police about the
incident. Traffic management teams representing state and local police and highway engineers
are gaining popularity as a way to develop response plans and traffic diversion routes. In any
given area there are usually several existing operation centers - police, traffic control, highway
maintenance, transit- that can also function as incident management centers. To be effective,
however, the personnel of the traffic operation center has be trained in dealing with incident
management.

Clearance
Private tow truck companies and hazmat clearing agencies handle the clearance of automobiles
and hazmat spills respectively. An effective clearance operation requires that the police officer
on the scene diagnose the problem and summon the equipment needed. Most police
departments do not provide specialized training in large truck incidents. Tow trucks often
arrive at the scene of large truck incidents with the wrong equipment and experience to handle
large incidents. These problems, often compounding, can double or triple the time required to
clear an incident, (Grenzeback 1992).
Recovery

Recovery consists of three steps: 1) redirecting the traffic flows at the site of the incident; 2) preventing more traffic from flowing into the area and getting trapped in the upstream queue; and 3) preventing congestion from spilling across the metropolitan traffic network. Incident congestion can be minimized by these actions, but traffic management is the least developed of most incident management programs. Whatever the method of detection, various response plans based upon the type of incident that occurs should be prepared in advance. Alternate routing, on-site coordination, communication, and the assignment of response personnel should all be prearranged.

Benefits and Implementation Issues

With the use of a freeway incident detection and management system, incident duration can be reduced by an average of 10 minutes. An FHWA study also revealed that such a system would reduce congestion on approximately 30% of the major urban freeway mileage. In Los Angeles, out of the total budget of $85,000 for 1984, a total of $30,000 was recovered directly from people involved in the incidents. This Freeway Incident Management systems also produced an estimated time savings of over one-half million dollars in reduced delay alone, producing a B/C ratio of 10:1.

This strategy produces effective reductions in delay due to improved service during off-peak and peak conditions. Table 4.10 presents expected reductions in delay for various strategies to improve the movement of traffic past the site of an incident and improve communications to the public to reduce the demand in the vicinity of an incident.
Table 4.10: Reduction in Delay Due to Improved Service Parameters

<table>
<thead>
<tr>
<th>Service Improvement</th>
<th>Delay Reduction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Flow</td>
<td>Off-Peak</td>
</tr>
<tr>
<td></td>
<td>Conditions (%)</td>
<td>Conditions (%)</td>
</tr>
<tr>
<td>5% Improvement in Bottleneck Flow Rate</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>10% Improvement in Bottleneck Flow Rate</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>25% Improvement in Bottleneck Flow Rate</td>
<td>38</td>
<td>88</td>
</tr>
<tr>
<td>25% Reduction in Clearance Time</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>50% Reduction in Clearance Time</td>
<td>19</td>
<td>44</td>
</tr>
<tr>
<td>20 Minute Earlier Demand Reduction</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>10% Demand Reduction after 40 Minutes</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>20% Demand Reduction after 40 Minutes</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>


Implementation issues to be considered are:

- The process from conceptual planning to a completed system of a freeway incident detection and management system will take 5 to 10 years, basically involving a long time frame and cannot be considered as a short term strategy to relieve congestion.
- Marketing efforts in a particular are essential to assure that public and elected officials will understand the impacts of these traffic management efforts.
- Including the proper traffic engineering, highway maintenance, and police personnel is essential to effective incident management.
- Coordination with local agencies, police and fire agencies, and other organizations as needed works to ensure cooperation in a rapid handling of highway incidents is also essential.

4.1.8 Motorist Information Systems

Motorist information systems represent one important element of a freeway incident management system. Motorist information is defined as information that allows motorists
to make accurate travel decisions. This information does not include only incident information, but information on recurring congestion, special events, trip mode options, and other factors that affects travel decisions.

Informed motorists can make decisions to divert around or stay away from an incident site, delay or change the time of a trip, or even change travel modes. To make such decisions the motorist must receive information in time to act on it. Even if an incident can’t be avoided, informed motorists are more tolerant of delay. Variable message signs (both fixed and portable), highway advisory radio, radio and television reports, and traffic reporting services are all means used today to advise motorists of all types of traffic information.

Benefits and Implementation Issues

Where these motorist information systems have been part of an integrated freeway surveillance and management system, they have proven to give potential benefits in reducing delays to relieve congestion. In 14 years of experience in the Los Angeles area, the California Department of Transportation has had several benefits due to their changeable message signs:

- Early warning reduced the speeds of vehicles approaching a queue, resulting in fewer secondary accidents and associated delay;
- Signing increased diversion at off-ramps that were greater than 1/2 mile upstream from incidents;
- Signing for lane blockages induced lane changing away from that lane; and
- Signs upstream from freeway-to-freeway interchanges were highly efficient.

The implementation issues to be considered are:

- Information must be in real-time and accurate;
- Nature of the system is such that experts in the areas of electronics and information systems must be involved in addition to highway and traffic engineers;
• The implementation should include local officials as well as the state highway departments; and

• Ideally, the motorist information system should be designed as an integral part of an areawide freeway management program for effectiveness.

4.1.9 Future Technologies

Innovative solutions are required if we have to learn how to control congestion in the coming years. In other words, we cannot only depend on traditional methods to apply for relieving congestion, but also find new solutions. Since the middle of the 1980’s, the California Department of Transportation has been pursuing a variety of solutions that take advantage of rapidly developing technological as a method of dealing with congestion and safety. The states of Michigan, Texas, and Massachusetts are also undertaking various research activities. The various efforts underway in the United States are being coordinated by an informal group called Mobility 2000. This group evolved from a series of meetings that began in 1987 and are moderated by the Federal Highway Administration. The group is composed of representatives from federal and state transportation agencies, universities, and vehicle manufacturers.

The scope of Mobility 2000 extends to all technologies that will improve the efficiency of the transportation system. It is concerned with Advanced Transportation Technology (ATT). Intelligent Vehicle Highway Systems (IVHS) are one essential element of ATT in that they concentrate on transportation operations, but do not include some of the broader aspects of transportation technology, including alternate fuels, robotics for maintenance and construction, and alternate modal systems. IVHS focuses on two of the nation’s most critical problems----congestion and safety.
What is IVHS?

Intelligent Vehicle Highway Systems (IVHS) is a highly diverse and interdisciplinary field. IVHS constitutes the incorporation of a number of technologies, including information processing, communications, control, and electronics, into the transportation system. The goal of IVHS is to develop a seamless intermodal transportation system that is economically efficient and environmentally sound, enabling the efficient movement of people and goods and thereby providing the foundation for the nation to compete in the global economy.

IVHS can multiply the effectiveness of future spending on highway construction and maintenance by increasing network wide efficiency. It can increase the attractiveness of public transportation by making it more convenient and economical to use. It is projected that by 2011, traffic fatalities will be reduced by at least 8%, and traffic congestion will be reduced by 20% in cities that adopt IVHS.

Six working groups have been established that correspond to the system areas associated with IVHS:

**Advanced Traffic Management Systems (ATMS)** employ innovative technologies and integrate new and existing traffic management and control systems in order to be responsive to dynamic traffic conditions while servicing all modes of transportation. Key features of ATMS are subsystem integration and real-time control adjustments that account for traffic fluctuations.

**Advanced Traveler Information Systems (ATIS)** acquire, analyze, communicate, and present information to assist surface transportation travelers in moving from a starting location (origin) to their desired destination. The systems provide assistance in such a manner that best satisfies the traveler's needs for safety, efficiency, and comfort. The
travel may involve a single mode of transportation, or it may link multiple modes together during various parts of the trip.

**Advanced Vehicle Control Systems (AVCS)** combine sensors, computers, and control systems in vehicles and in the infrastructure to warn and assist drivers or to intervene in the driving task. The purposes of AVCS include achieving much higher vehicle safety levels, ameliorating urban freeway congestion, achieving a new standard of intercity highway productivity, and eventually creating entirely new concepts for surface transportation services. AVCS encompasses a broad range of products and systems that will become operational on different time scales.

**Commercial Vehicle Operations (CVO)** systems apply various IVHS technologies to improve the safety and efficiency of commercial vehicle and fleet operations. For our purpose, commercial vehicles include trucks, delivery vans, inter-city buses, and emergency vehicles. CVO systems increase safety, expedite deliveries, improve operational efficiency, improve incident response, and decrease operational costs.

**Advanced Public Transportation Systems (APTS)** encompasses the application of advanced electronic technologies to the deployment and operation of high occupancy, shared-ride vehicles, including conventional buses, rail vehicles, and the entire range of para-transit vehicles. APTS will keep the traveler informed, in real time, of any system changes in the traveler’s plans. These systems will help the vehicle system administrators manage a safe and efficient fleet and plan services to meet a broad range of consumer needs. They will also enable transit authorities to provide a more flexible, cost effective, and user-friendly service to their customers.

**Advanced Rural Transportation Systems (ARTS)** provides integration of IVHS user services to address the rural travel environment. ARTS recognizes that there are
characteristic differences between urban and rural travel. For example, urban travelers experience higher traffic volumes at slower speeds for short distances while rural travel involves lower traffic volumes, usually at higher speeds. As a result, urban travelers are concerned about congestion and personal security while rural travelers are more concerned with traveler services and safety.

The three main components of IVHS that are most directly related to reducing urban area congestion are Advanced Traffic Management Systems (ATMS), Advanced Driver Information Systems (ADIS), and Automated Vehicle Control Systems (AVCS).

They are six primary characteristics that differentiate ATMS from the typical traffic management systems of today:

- An ATMS works in real time;
- ATMS estimates when and where congestion will take place and take steps to prevent it from occurring;
- ATMS includes areawide surveillance and detection systems, allowing total system evaluation and/or analysis;
- ATMS integrates control of various facilities (integrated freeway and arterial management);
- An ATMS implies collaborative actions; adjacent jurisdictions will work in cooperation with each other; and
- An ATMS includes rapid response incident management strategies (rapid detection, verification and appropriate response plans) and integrated diversion strategies.

Not only will ATMS be able to manage transportation systems, but these systems will also serve as a valuable, comprehensive database. The implementation of ATMS is the preliminary step towards a comprehensive IVHS. They are currently 29 state-of-the-art
systems in the United States that are either under development or are already partially operational.

AVCS aims to improve highway capacity by permitting vehicles to operate with smaller longitudinal and lateral spacing while traveling at higher speeds without sacrificing safety. AVCS also attempts to improve highway safety with sensors, automated steering, automated braking and automated acceleration.

ATIS technologies will provide information to travelers on:

- Location within the network
- Travel times
- The best and alternate routes
- Areas of congestion
- Safety advisories
- Construction activities
- Status of HOV lanes, parking lots, transit

ATIS features and products include:

- Navigation systems with electronic vehicle or traveler position determination;
- Data communication: transceivers providing information to, and receiving information from, traffic management centers;
- Route planning and guidance systems;
- Automated vehicle identification (AVI) systems for uses such as transit vehicle tracking or commercial vehicle credential processing;
- Flexible driver visual interface for displaying maps or traffic information;
- Warning systems for various operational and maintenance conditions on transit, commercial, or private vehicles;
- Emergency (Mayday) services with signaling and response capabilities;
- A wide variety of databases, including detailed maps, business directories, transit schedules, tourist information and the location of various services;
• Integrated ATIS/AVCS that channel AVCS control and driver condition warnings through ATIS; and

• Dynamic route guidance that can reroute vehicles around traffic congestion or incidents.

Benefits and Implementation Issues
The ultimate goal of the individual systems discussed is to work in combination to form an IVHS. The benefits expected from such an application include decreased urban area congestion, improved highway safety, decreased vehicle emissions, and decreased fuel consumption.

When considering implementation issues it must be realized that many of these technologies are in the future and will not be available for some time. Due to the high financial expense typically associated with the state of the art technology, the cost of these systems will likely be the most important implementation factor. Transportation agencies in major urban areas will need to decide whether the benefits associated with IVHS are worth the significant investments required for their implementation.
5.0 CASE STUDIES

The original concept of a freeway was that of a facility on which large volumes of traffic would move at high speeds. Also, it was thought that these superhighways would operate properly with little or no attention from public agencies. During most hours of the day, this concept is correct. During other periods of the day, many urban freeways are plagued by recurring peak-period congestion that is caused by the traffic demand exceeding the capacity of the facilities. This is a fact known to transportation professionals, and though a great deal of progress has been made and many accomplishments achieved, the congestion problem only seems to have worsened instead of reducing. This is because urban transportation study results, although as good as possible, are simply not accurate enough for purposes of facility design, and there are unforeseen changes in land use or development changing the travel patterns in the area. Another reason could be attributed to the fact that transportation planners use traffic assignments based on transportation networks that are planned for completion 20 years in future. However, until the planning horizon is reached, partial systems are in operation, and portions of these systems must carry the loads that will later be handled by new facilities.

As a result of these needs, several groups have began looking at problems and seeking solutions. In the following, a review of some of these accomplishments by different agencies from both the United States and other developing countries are shown. The approach involves an evaluation of certain case studies for respective supply measures.

Each case study will be reviewed with a brief description of the setting of the project, the project objectives, and, finally, the benefits and impacts of the particular strategy if any. By reviewing these case studies, we will have a better idea on the various strategies to be
applied to future projects along with a perspective to implementation issues and barriers to be considered in applying the specific supply measure to alleviate congestion.

5.1 IMPROVED CONTROL DEVICES

5.1.1 West German Variable Speed Limits

As in other countries, traffic on the German freeways is increasingly characterized by high traffic flows and, in particular, by regularly occurring high peaks. Studies have been carried out to see whether the safe and efficient handling of these peaks can be influenced by control measures in order to attain optimum flow.

Program

A program was started on a 20 mile section of the Munich-Salzburg Autobahn. The main objective of the program was to attain optimum flow on the freeway. The definition of optimum flow for this setting was:

- Spacing and speeds of the vehicles along the road are such as to permit maximum safety and capacity;
- In the event of an unforeseen obstruction of a lane, the vehicles can be diverted before reaching the obstruction so that major holdups could be avoided;
- Drivers are advised by remotely controlled signs and signals about the traffic conditions on the road ahead and about any hazards on the way, so that they have ample time to adapt themselves to the situation.

The program included the following:

- Variable remotely controlled signs and signals on the section capable of imposing variable speed restrictions, depending on the momentary traffic volumes;
• Providing advance warning of accidents on the section;
• Diverting traffic through one of the autobahn exits to the all-purpose road network.

The first areas were implemented with remotely controlled variable signs of the roller-blind type capable of giving the following indication: 100km, 80km, 60km, End of Speed Restriction, and Accident Ahead. The signs show a speed limit of 100 km/hr when traffic flow is below 2000 cars/hour, and are changed to 80 km/hr when this rate is reached. These signs are installed at intervals of just more than a mile apart. Traffic diversion was done by means of two signal bridges that span the carriageway at intervals of 1200ft, together with colored-light signs for the control of traffic on each lane.

Results
• Higher capacity was obtained when signs were displayed (2000km/hr with the 80km/hr).
• When no speed limits were shown, 35% of vehicles exceeded 100km/hr and 90% exceeded 95km/hr.
• When speed limits were shown no drivers exceeded 110km/hr. When the sign showed 100km/hr, 38% exceeded 95km/hr and when 80km/hr was shown 8% exceeded 95km/hr.

Due to the success of this section, more heavily traveled autobahn sections are being equipped with similar signs and detectors.

5.1.2 Japan Urban Freeway

Setting
The Hanshin Expressway is an Urban freeway system in the metropolitan Osaka and Kobe areas of Japan. In metro Tokyo, there are at present 45 miles of urban freeway. There are
an average of 350,000 trips, ten accidents and 50 breakdowns per day on the expressway. Congestion is defined as a queue greater than 0.6 miles in length.

Program
A central control room monitors conditions on the expressway and provides information to drivers on changeable message signs. Presently there are 61 changeable signs in Tokyo and 38 signs in Hanshin. Information is given to drivers on congestion causes, including congestion caused by excess demand, accidents, or vehicle breakdowns.

Results
The implementation of the signs showed improvements in reducing congestion based on the various conditions under which they were used.

5.2 TRAFFIC SIGNAL IMPROVEMENTS

5.2.1 CALIFORNIA’S Fuel Efficient Traffic Signal Timing Program (FETSIM)

Setting
The California Energy Commission, with CALTRANS and Institute of Transportation Studies (ITS), organized the Fuel Efficient Traffic Signal Timing Program (FETSIM) to optimize signals in 61 cities and 1 county in California in 1986, to improve fuel efficiency and reduce congestion.

Program
The principal objective was to reduce vehicle stops and delays to alleviate congestion and reduce fuel consumption. A before and after simulation model and field tests were conducted. Out of 22,500 signals, 10,000 of them had the necessary technology, while the
remainder needed to be upgraded with some minor equipment changes. By 1987, 5200 signalized intersections were retimed.

**Results**

The program cost about $1400 per intersection. Results of the program included:

- Vehicle delays reduced by 15%;
- Vehicle stops reduced by 16%;
- Travel times reduced by 7%;
- Fuel consumption reduced by 8.6%;
- Average fuel savings of 6000 gallons/intersection;
- Reduced emissions and improved traffic operations database;
- B/C ratio of 58:1 to the road user.

Other potential benefits of the FETSIM are:

a) Better functioning signals, since the program provided the opportunity to systematically check and repair equipment.

b) An indication of improvements needed in signal system hardware

c) A better traffic data base, which many cities use in other planning studies and project analyses.

d) A promotion of inter-agency communication, cooperation and coordination between local and state agencies.

### 5.2.2 Los Angeles Automated Traffic Surveillance and Control (ATSAC) System

The goal of ATSAC is to provide a flexible tool for improved traffic signal system management. Major areas of emphasis are identification of equipment malfunctions, adapting timing plans to short and long term fluctuations in traffic demand, and responding to non-recurring changes in traffic patterns caused by special events, accidents, and construction activity.
Setting
The first phase of the ATSAC system was installed during the 1984 Olympics to better coordinate traffic around the Los Angeles Coliseum. Since that time, ATSAC has been in continuous operation, new features have been added to the system, and implementation in other areas are underway.

Program
The initial ATSAC installation encompassed 118 intersections and 396 detectors in a 4 square mile area located 5 miles from the ATSAC control center. Two major freeways pass through the control area, the Santa Monica freeway on the north and the Harbor freeway on the south. The system is now the most advanced signal control system in the United States. A 1987 evaluation of the ATSAC examined changes in traffic of the system before and after, and of 118 traffic signals and 396 system detectors.

The second phase of the system concentrates on the Los Angeles CBD comprised of 162 intersection signals, 49 mid-block signals, and 800 detectors. The third and fourth phases are currently under design and should be fully implemented soon.

Some of the distinguishing features of the ATSAC System are:
- It is one of the first computer signal control systems to utilize the UTCS Enhanced software package;
- The street network is heavily detectorized;
- Computer generated color graphics displays are used rather than map boards;
- Critical Intersection Control (CIC) is operated at a large number of locations;
- Performance measures are computed in real-time using detector data;
- I-5 Generation control will be used for timing plan updates;
- Fiber optics is used for trunk communications;
- Type 170 controllers are used at all intersections.
Results

Some potential benefits of the program include:

- 13% reduction in vehicle delays;
- 35% reduction in vehicle stops;
- 14% increase in average speed;
- 20% decrease in intersection delay;
- 12.5% decrease in fuel consumption;
- 10% decrease in hydrocarbon emissions and 10% in carbon monoxide emissions;
- B/C ratio of 9.8:1.

The ATSAC System has given Los Angeles the capability to respond more effectively to short term and long term changes in traffic demand, develop new signal timing plans, evaluate the performance of current timing strategies, and identify equipment malfunctions.

5.3 IMPROVED INTERSECTIONS

5.3.1 US 70 Corridor

US 70 has long been a critical East-West route in the eastern and central parts of North Carolina. Large increases of motor vehicle traffic on the corridor, particularly the section of the route between Raleigh and the Morehead City/Beaufort area, has strained the road capacity and resulted in unacceptable levels of congestion in several towns and cities along the route. This increased congestion has a negative impact on the quality of life due to unnecessary traffic delays, unnecessary noise, and driver frustration. Also on the US 70 corridor, maintaining acceptable driving conditions for the high level of tourist traffic was
considered especially significant, along with providing better quality peak traffic operation for local residents and businesses in towns and cities along the route.

Program
A comprehensive study was performed along this corridor to identify congested areas and benefits of congestion management techniques. Basic techniques to improve the traffic capacity of existing roadways through increasing the efficiency of traffic signal system operations were found to be the most appropriate. A closed loop coordinated system on several intersections of the US 70 Corridor was suggested. The program had the following objectives:

- To implement an enhanced actuated operation called "volume density" at 24 isolated intersections. The "volume density" application is a feature of the newer controllers and is designed to give a longer green signal to an approach when traffic on that approach is heavy. Out of the 24 intersections, volume density has already been implemented for 20 of the intersections.

- Form traffic responsive coordinated closed loop signal systems with appropriate signal timing plans for groups of signals. Coordination allows signals at adjacent signalized intersections to operate in a coordinated manner so as to enable motorists to pass through a series of signalized intersections with minimum delay and traffic congestion.

- Replace existing manually tuned analog vehicle detectors with self timing digital vehicle detectors at all actuated signals. Proper operation of vehicle detectors is critical to efficient traffic signal operation since detector inputs to the controller determine signal sequence and timing to a great degree. The self-tuning digital detector units are capable of automatically tuning out any environmental changes in the detection circuit.

- The last strategy involved the addition of lane capacity on US 70 in Havelock by means of widening a 9/10 of a mile section of roadway and remarking the lanes in an additional 1.4 miles of roadway. This project would add an additional lane in each
direction for through traffic on 2.3 miles of the most congested portion of the US 70 in Havelock, as well as adding a right turn lane at the most congested intersection.

Results

The following is a summary (Ref. 5.1) of the total estimated average delay experienced by motorists driving through each intersection in the three proposed systems under current operating conditions and after the implementation of the various US corridor closed loop systems. The delay times shown below are the average delay at any given intersection in the proposed system locations. With the installation of the closed loop system, an average of 50 to 70% reduction in delays were obtained.

Table 5.1: Results of the Average Delay Savings with the Implementation of the Closed Loop System

| Location | Peak Period | Calculated Present Average Delay (Seconds) | Estimated Average Delay with Closed Loop System (Seconds) | Average Improvement
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seconds</td>
</tr>
<tr>
<td>Selma</td>
<td>AM</td>
<td>43.3</td>
<td>19.3</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>115.0</td>
<td>32.1</td>
<td>82.9</td>
</tr>
<tr>
<td></td>
<td>Noon</td>
<td>69.6</td>
<td>20.6</td>
<td>49.0</td>
</tr>
<tr>
<td>Havelock</td>
<td>AM</td>
<td>78.0</td>
<td>22.0</td>
<td>56.0</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>113.5</td>
<td>57.6</td>
<td>55.9</td>
</tr>
<tr>
<td></td>
<td>Noon</td>
<td>26.4</td>
<td>17.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Morehead</td>
<td>AM</td>
<td>36.9</td>
<td>12.4</td>
<td>24.5</td>
</tr>
<tr>
<td>City</td>
<td>PM</td>
<td>41.7</td>
<td>20.9</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>Noon</td>
<td>34.2</td>
<td>13.3</td>
<td>20.9</td>
</tr>
</tbody>
</table>

(Source: Congestion Management Study: US 70 Corridor, Raleigh to Beaufort, NCDOT, 1991)

The following table (Ref. Table 5.2) is a summary of the total estimated project costs and total estimated annual peak hour fuel savings to motorists resulting from the implementation of the various US 70 corridor closed loop systems. Estimated annual peak hour savings lie in the range of $90,000-$125,000.
Table 5.2: Estimated Annual Peak Hour Fuel Savings with Implementation of Closed Loop System

<table>
<thead>
<tr>
<th>System Location</th>
<th>Estimated Total Closed Loop Project Cost ($)</th>
<th>Estimated Annual Peak Hour Fuel Savings ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selma</td>
<td>115,940.00</td>
<td>125,468.75</td>
</tr>
<tr>
<td>Havelock</td>
<td>187,849.00</td>
<td>181,529.69</td>
</tr>
<tr>
<td>Morehead City</td>
<td>174,101.00</td>
<td>93,816.41</td>
</tr>
</tbody>
</table>

(Source: Congestion Management Study: US 70 Corridor, Raleigh to Beaufort, NCDOT, 1991)

5.4 RAMP METERING

A study was performed by Farradyne Systems, Inc. in 1992 on Coordinated Operation of Ramp Metering and Adjacent Traffic Signal Control Systems. This project involved research to develop coordinated traffic control strategies that will improve the operational performance of computerized corridor management systems and reduce urban congestion.

In most ramp metering systems, the operational emphasis is placed on managing traffic from the perspective of optimizing freeway traffic flow. In many respects, the ramps function as traffic-demand surge-suppression devices to achieve maximum flow rates on the freeway. Conversely, in existing traffic signal systems, emphasis is placed on optimizing traffic flows within the surface street network, and little or no thought is given to freeway control issues.

Problem Identification

One of the existing solutions for the freeway system is an integrated ramp metering systems strategy that changes the metering rates to optimize freeway flow. This strategy may result in an on-ramp queue backup that causes spillback and affects the operation of the signalized intersection. Many freeway surveillance and control systems have a
presence loop detector at the upstream end of an on-ramp. Ramp queue buildup is sensed with this detector. When this happens, the metering rate is increased and excessive queues are formed regardless of the negative impact of the freeway flow.

The solution to the above problems is integration of traffic signal operation with the ramp controller. This will provide other alternatives to control traffic flow, both on the freeway and within the arterial system. Capacity reduction could be achieved by increasing all red clearance intervals in the signal cycle.

**Program**
The objective of the system was to develop overall strategies and user guidelines for the coordinated operation of ramp metering and adjacent traffic signal systems. The project also aimed at testing and evaluation of the developed operating strategies using computer simulation for two potential sites.

**Operating Strategies**
Coordinated or integrated ramp metering operation aims at integration of adjacent traffic control system and ramp metering system. Ramp metering rates are determined in accordance with freeway flow and adjacent arterial traffic conditions, i.e., traffic situations throughout the area-wide system. This type of operation provides other alternatives to control traffic flow both on the freeway and within the arterial system. For example, access to the ramp could be limited by reducing the capacity of the signalized intersection. Capacity reduction could be achieved by increasing all red clearance intervals in the signal cycle. The control of each ramp is based on the available capacity considerations for the whole system, rather than on the available capacity constraint at each individual ramp. Figure 5.1 depicts the conceptual design for the integration system.
Figure 5.1: Conceptual Design for Integration System
Control Tactics

The control tactics are the results of interaction between local traffic signal controllers and ramp meter controllers. Table 5.3 shows that seven different optimization tactics can be used at any given intersection-ramp location and the remaining tactics can be employed within the corridor on arterial streets.

Table 5.3: Relationship between Strategies and Tactics

<table>
<thead>
<tr>
<th>Tactics</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Local</td>
</tr>
<tr>
<td><strong>Corridor Related Tactics</strong></td>
<td></td>
</tr>
<tr>
<td>Inhibit metering</td>
<td></td>
</tr>
<tr>
<td>Simultaneous Offsets</td>
<td></td>
</tr>
<tr>
<td>Short cycling</td>
<td></td>
</tr>
<tr>
<td>Double cycling</td>
<td></td>
</tr>
<tr>
<td>Reverse progression</td>
<td></td>
</tr>
<tr>
<td>Green metering</td>
<td></td>
</tr>
<tr>
<td>All red extension</td>
<td></td>
</tr>
<tr>
<td><strong>Interchange Area Tactics</strong></td>
<td></td>
</tr>
<tr>
<td>Off-ramp priority</td>
<td></td>
</tr>
<tr>
<td>On-ramp access control</td>
<td></td>
</tr>
<tr>
<td>Arterial priority</td>
<td></td>
</tr>
<tr>
<td>Freeway priority</td>
<td></td>
</tr>
<tr>
<td>On-ramp priority</td>
<td></td>
</tr>
<tr>
<td>Equity offset</td>
<td></td>
</tr>
<tr>
<td>Queue management</td>
<td></td>
</tr>
<tr>
<td>Demand storage</td>
<td></td>
</tr>
<tr>
<td>Inhibit metering</td>
<td></td>
</tr>
<tr>
<td>Ramp closure</td>
<td></td>
</tr>
</tbody>
</table>


Simulation Study

Simulation of the operating strategies had been performed using a microscopic simulation package, INTRAS (INtegrated Traffic Simulation). Study sites were:

- **Seattle, WA I-5/SR 99 Corridor**: This corridor is located north of Seattle’s city limits and consists of the I-5 freeway that runs north-south through the Seattle area
and the parallel arterial State Route 99 both operated by the Washington State Department of Transportation (WSDOT). The corridor, 6.7 miles in length, includes 7 interchanges with 11 ramp controllers operating in both directions. The ramp metering system is an integrated traffic-responsive system that employs areawide traffic conditions to calculate metering rates in real-time. The corridor is controlled by a regionwide transportation management system that included ramp control, park-and-ride lots, freeway flyer stops, high occupancy vehicle (HOV) lanes, operation of the arterial control system, and operation of a reversible lane control system.

- Westminster-Garden Grove, CA Garden Grove Corridor: This runs east-west parallel to the Garden Grove Freeway (California Route 22), the major freeway between the cities of Westminster, Garden Grove, and Santa Ana. The corridor is 7 miles and has 4 interchanges. There are two major arterials which are parallel to the corridor: Garden Grove Boulevard, north of the freeway, and Westminster Avenue in the south. All these arterials are on the Garden Grove central master system and there is no interconnection between ramp signals and intersections. The ramp metering system uses different methods, such as clock-time metering and gap acceptance merge control, to control the ramps.

Three cases of traffic control strategies were specified to investigate the operational sensitivities of different levels of integrated control strategies:

- **Local coordinated strategy:** In this case, the network was under the control of existing traffic management systems, which were subjected to two different traffic loading conditions and two levels of incident severity. The existing ramp metering rates and signal timing plans at each site, for the morning peak period, were used in the simulation.
- **Minimum operation:** This case considered minimum interaction between the freeway and arterial signal systems. Areawide ramp control for the freeway and adjustment of traffic signal timing for the arterial, were considered.

- **Maximum coordination:** This case used several combinations of control tactics to improve existing traffic control on both freeway and arterial street systems with maximum interaction between both freeway and arterial signal coordination. For the freeway, integrated areawide ramp control was in effect. In addition, the entrance ramp located upstream from the incident was immediately closed after the incident occurred. The exit ramp queue detector was modeled to avoid spillback onto the freeway. Maximum priority was given to both ramp traffic from the exit ramps and to traffic moving onto the entrance ramp.

**Results**

Figure 5.2 depicts the benefits of applied strategies on the network traffic performance for a moderate volume level with severe incidents at both sites. It is evident that minimum and maximum coordinated operation have improved traffic flow over the network.

- For Seattle I-5, reduction in total delay using minimum coordination (60% volume and 30% incident diversion), over local coordination, was 26%.
- For Seattle I-5, reduction in total delay using maximum coordination (100% volume and 30% incident diversion) over local coordination, was 33%.
- In the case of Garden Grove corridor, the reduction in total delay for minimum and maximum coordination over local coordination were 4% and 8% respectively.
- The high degree of improvement of Seattle I-5 is the result of the integrated ramp metering system and the queue override feature that were not available in the Garden Grove corridor.
Figure 5.2. Network Total Delay

This study proved that the integrated ramp metering operation is the most effective in improving freeway traffic flow and adjacent arterial traffic flow. It was concluded that the main requirement for implementation of the integration system is the development of operating software to perform communication between the three control systems: the Central System, the Arterial Signal System, and the Integration System. It was also concluded that the above results could be applicable to most of the existing corridors within the United States that meet the requirements.
5.5 SUPER STREET ARTERIALS

5.5.1 Houston SUPER STREET ARTERIAL

The potential impact of a network of regional arterials on typical large, automobile-oriented urban areas was examined through a simulation study of the Houston regional urban area. The simulation was performed using the Texas Large Network Computer Package running on the Texas Department of Transportation mainframe computer system. Assigned traffic consisted of the forecast year 2010 daily highway volumes and the planned 2010 regional highway system.

Program
The simulation consisted of only a very general set of modifications to the planned 2010 regional highway. Two simulations were conducted on a 350 mile strategic system and 600 mile strategic system.

- As indicated in the Table 5.4, the approximate 350 mile strategic arterial system was composed of 337 miles of upgraded existing street alignment with only 15 new centerline miles.
- The more extensive, roughly 600 mile system included 519 miles of upgraded street and only 62 new centerline miles.

The modifications planned for the two sets of simulations were:

- Addition of links composing 15 and 62 new centerline miles for the 350 and 600 mile strategic arterial system, respectively;
- Speed increases of 5 or 10mph (two different cases) on the links of the strategic arterial systems. These increases were applied to the normal arterial speeds;
- Appropriate capacity specifications for the links of the strategic arterials; and
- Decreases in link capacities for links crossing the strategic arterial.
Table 5.4: Alternative Regional Arterial Network for Houston Region

<table>
<thead>
<tr>
<th>Facility Class</th>
<th>350 Mile Strategic Arterial System Total Centerline Miles</th>
<th>600 Mile Strategic Arterial System Total Centerline Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway</td>
<td>875</td>
<td>875</td>
</tr>
<tr>
<td>Facility to be Upgraded to Strategic Arterial</td>
<td>352</td>
<td>581</td>
</tr>
<tr>
<td>Principal Arterial</td>
<td>447</td>
<td>440</td>
</tr>
<tr>
<td>Other Arterial</td>
<td>2546</td>
<td>2428</td>
</tr>
<tr>
<td>Collector</td>
<td>2352</td>
<td>2294</td>
</tr>
</tbody>
</table>

(Source: Transportation Research Record, 1360)

Several arterial improvement concepts were not simulated. These included control or prohibition of left turns, and grade separations. The simulation study represented an approximate potential effects worst case. The modeling system used was based on daily traffic and not hourly demands. Summary statistics for the two alternative regional arterial systems that were examined are detailed below.

Results

For the 350 mile Strategic Arterial System

- The 10mph increase for regional arterials produced weighted average speeds of 48mph, caused more diversion from freeways and other facilities to the regional arterial facility class. As Table 5.5 the 350-mile system would reduce freeway Daily Vehicle Miles Traveled (DVMT) by 3 to 4 percent, have minimal impact on other facility classes, and double DVMT on the facility redesignated as regional arterials.
- Almost 20% of the 1,042 freeway links included in the simulation had daily traffic volumes reduced by more than 10,000, which may be far more significant than the DVMT reductions.
Table 5.5: Effects of the 350-mi. Strategic Arterial System

<table>
<thead>
<tr>
<th>Facility Class</th>
<th>Assigned Daily Vehicle Miles of Travel (000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Network</td>
</tr>
<tr>
<td>Freeway</td>
<td>55,246</td>
</tr>
<tr>
<td>Strategic Arterial</td>
<td>5,831</td>
</tr>
<tr>
<td>Principal Arterial</td>
<td>6,347</td>
</tr>
<tr>
<td>Other Arterial</td>
<td>25,690</td>
</tr>
<tr>
<td>Collector</td>
<td>2,132</td>
</tr>
</tbody>
</table>

(Source: Transportation Research Record, 1360)

For the 600 mile Strategic Arterial System

- For this system, freeway DVMT was reduced roughly by 6 percent, and nearly 30% of the 1042 freeway links included had average daily traffic volumes reduced by more than 10,000. Table 5.6 shows the effects of the 600 mile strategic arterial system.

Table 5.6: Effects of the 600-mi. Strategic Arterial System

<table>
<thead>
<tr>
<th>Facility Class</th>
<th>Assigned Daily Vehicle Miles of Travel (000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Network</td>
</tr>
<tr>
<td>Freeway</td>
<td>55,246</td>
</tr>
<tr>
<td>Strategic Arterial</td>
<td>7,939</td>
</tr>
<tr>
<td>Principal Arterial</td>
<td>6,255</td>
</tr>
<tr>
<td>Other Arterial</td>
<td>23,872</td>
</tr>
<tr>
<td>Collector</td>
<td>1,934</td>
</tr>
</tbody>
</table>

(Source: Transportation Research Record, 1360)

The study indicated that the regional arterial street concepts are practically implementable and offer great potential highway user benefits. The key element, however, is a highly disciplined operating policy that guarantees the maintenance of the specific features so as to obtain maximum efficiency.
5.6 EXCLUSIVE BUS LANES

5.6.1 Bangkok Bus Lanes

In order to deal with the widespread and growing congestion in Bangkok, the Thailand Government in 1978 embarked on a comprehensive urban transport scheme. The project was designed to strengthen urban transport management, increase the capacity of the road network, and improve public transport.

Program

The project was aimed at providing extensive priority bus measures. At the time of the project, bus trips in the central area during peak periods were as slow as 10km/hr, while cars had 12km/hr. As in other developing cities, more than 60% of all personal trips on the main roads in Bangkok were made in buses and minibuses, which together accounted for only 6% of all passenger vehicles. Private cars, which made up more than half of the traffic (57% of all vehicles), carried only 26% of the commuters. Both types of vehicles were caught in traffic snarls. Then, in 1980, 145 kilometers of traffic lanes were set aside for the exclusive use of buses.

Results

• Due to these comprehensive measures, both bus and car travel times improved significantly in almost all cases. In areas where the most success was achieved, bus and car travel times reduced by 25 to 30 percent.

• Observed bus flows were very high, with up to 250 standard buses and 150 private minibuses using a single bus lane during an average peak hour. These vehicles had a carrying capacity of 18,000 passengers per hour.
The total project costs were less than $1.5 million dollars, but the benefits outweigh the costs by far. Intensive utilization of a single lane of traffic indicates that road space can be efficiently used if the appropriate measures are introduced. The results also indicated that 20% of the vehicles in the priority bus lanes were illegal users, mainly slow-moving nonmotorized vehicles. This suggested that strengthened enforcement might lead to even better results.

5.6.2 Exclusive Busways In Porto Alegre, Brazil

In Porto Alegre, Brazil, the designated expressway is very narrow, and it is impossible for other vehicles to pass at bus stops. Buses are often held up by those stopped ahead, thus leading to extreme delays and queues.

Program

In 1978, the administration of Porto Alegre set aside 30 kilometers of road as exclusive busways. In this way, the city has been able to accommodate high passenger flows in the CBD without having to invest in costly elevated or underground systems. The program included paving expressways, erecting bus stops, posting signs and marking right-of-way by curbs or low reflectors. The solution for narrow expressways was found in the bus convoy or Comonor. At the beginning of a corridor, buses are coordinated in a fixed sequence according to their route and form convoys of up to six buses. At each bus stop, a passenger awaits his bus at a "subgroup" bus stop coinciding with his bus location in the convoy.

Results

- A convoy can almost double busway capacity in congested areas. The combined use of the bus expressway and the bus convoy has achieved peak-hour one-way passenger
flows of 28,000 passengers on 260 buses at an average speed of 19km/hour in the most heavily traveled corridor.

- Higher speeds have also been achieved by the use of efficient transfer terminals for the buses which had led to unnecessary congestion when feeder routes overlapped in the downtown area. The strategy was to have two transfer terminals where passengers would transfer between the smaller and larger buses. This strategy resulted in 20% higher speeds and corresponding fuel savings.

5.6.3 Comprehensive Transport System In Abidjan, Ivory Coast

Ivory Coast adopted a comprehensive approach to improving the transport system in Abidjan. Various low-cost transportation supply measures were seen as effective alternative solutions. The strategies implemented were:

- Traffic was improved by creating one-way streets, installing integrated traffic signals, signs, and road markings in the central business district, and extending traffic management programs throughout the city.

- Traffic management measures were introduced to improve the movement of pedestrians and buses in high-density, low-income communities.

- Pedestrian facilities were constructed, including footbridges.

- Busways and reserved bus lanes were established in the central business district.

- A high-speed express bus network was created by constructing new road links.

- Bus terminals and bus stops were upgraded and a bus depot constructed.

- Primary roads were constructed to improve public transport access to low-income areas.

Before these improvements were made, key sections of the city’s road network were seriously overloaded, and the congestion lasted for as long as 12 hours each day.
Results

- Considerable all-round improvement has occurred as a result of the project. Buses now cross the central business district in half the time and other traffic has benefited from the elimination of congestion caused by the loading and unloading of buses.
- The city was able to achieve these improvements even though rush-hour traffic increased by roughly 20 to 30%.

By making better use of the existing road network and other transport facilities, Abidjan found it possible to forgo or defer several expensive infrastructure projects.

5.6.4 Second Avenue Bus Lane, New York

An evening outbound express bus runs from the Manhattan CBD to suburban Queens experienced significant delays compared to the morning inbound runs as they used different routes. Express bus ridership was 20% less in the evening service than that carried in the morning. Outbound express buses were hampered by 2 major factors in the Queensboro Bridge area. First, traffic increased 26% on the untolled bridge during the years 1970-1979. Second, the bridge's upper roadway was closed to buses in 1972 because it was deemed structurally too weak to accommodate them.

Analysis of the above problem led to the requirement of a contra-flow bus lane. The purpose of this lane was to speed up the evening outbound express buses reaching the Queensboro Bridge. The need became increasingly more pronounced as it became clear that the lead time, high capital costs, and administrative complexity of new subway construction to serve the burgeoning east midtown area of Manhattan made these projects impossible to implement in the foreseeable future. The city was particularly interested in fostering express bus ridership in order to draw as many Manhattan-bound commuters as possible from using automobiles.
Program
Thirty of the 70 available feet of Second Avenue is reserved for the exclusive bus lane. A yellow double-striped line separates the 18' contra flow lane from the southbound lanes. The lane, which extends 2 blocks, has three signalized intersections and carries by about 250 buses in the 4:00-6:00pm peak period. The main objectives of the program were:

- to expedite express bus flow during the evening rush hours for buses using the Queensboro Bridge;
- to reduce traffic congestion on the Manhattan side of the Queensboro bridge approaches;
- to encourage higher evening utilization of express buses heading to the outlying areas of Queens county; and
- to improve efficiency of express bus service.

Results
The following results were obtained after conducting traffic studies and evaluating the performance of the contra-flow bus lane:

- Buses saved an average of 1 to 2 minutes per trip and up to 7 minutes during the most congested period;
- Bus speeds increased from 8.6 to 9.7 mph respectively;
- Annual bus miles saved were estimated to be 5,200;
- Total passenger time savings amounted to 43,000 passenger hours per year;
- The 5,200 miles saved annually are equivalent to 1,730 gallons of diesel fuel;
- In its first sixteen months of operation, no pedestrian or traffic accidents could be directly attributed to the bus lane;
- Ridership rose up from 5,355,000 (1977) to 6,772,000 (1979);
- Reduced pollution was also achieved due to reduced bus VMT. Thirty two percent less hydrocarbons, 33% less carbon monoxide and 32% less nitrous oxide were reported.
Table 5.7: Results of Traffic Studies 1972

<table>
<thead>
<tr>
<th>Route</th>
<th>No. of Bases</th>
<th>Before (min.)</th>
<th>After (min.)</th>
<th>Difference (min.)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th Avenue to Queens Boulevard</td>
<td>60</td>
<td>26</td>
<td>20</td>
<td>-6</td>
<td>-23%</td>
</tr>
<tr>
<td>6th Avenue to Northern Boulevard</td>
<td>30</td>
<td>29</td>
<td>28</td>
<td>-1</td>
<td>-3%</td>
</tr>
<tr>
<td>3rd Avenue to Queens Boulevard</td>
<td>30</td>
<td>14</td>
<td>8</td>
<td>-6</td>
<td>-43%</td>
</tr>
<tr>
<td>Madison Avenue to Queens Boulevard</td>
<td>30</td>
<td>22</td>
<td>13</td>
<td>-9</td>
<td>-40%</td>
</tr>
<tr>
<td>Total</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Time Savings/Trip (Queens Boulevard) 7 Minutes
Average Time Savings/Trip to Northern Boulevard 1 Minute

(Source: Transportation Systems Management-Implementation and Impacts, 1982)

From the implementation of the above project, it was realized that there are essentially two qualities a bus lane project should have: 1) sufficient width for bus passing, and 2) sufficient traffic congestion to warrant exclusive treatment and gain significant travel time advantages.

5.6.5 Exclusive Bus Lane Projects in the United States

One of the Urban Mass Transportation Administration's (UMTA) and Federal Highway's (FHWA) earliest High Occupancy Vehicle (HOV) projects was known as the Bus Priority Demonstration Program. This project was done in Seattle, Washington. This program has since become known as the Blue Streak Project, and was conceived in the late 1960's by Don Smith of Seattle Transit. This project included a 500 car park-and-ride lot near the Northgate Shopping Center about 8 miles north on I-5, express buses on the reversible lanes of I-5, and an exclusive bus off-ramp connection to the Central Business District (CBD) streets.
There are several examples of dedicated bus/transit lanes in the United States. They stretch across the country and are located in large urban areas. Some important ones are discussed below:

- The first HOV lanes in Pittsburgh were concurrent bus lanes in the downtown area. These lanes were implemented in 1977, and were used to let buses move through the downtown area faster. Additional contra-flow lanes were added on streets approaching the downtown area and in the area close to the University of Pittsburgh. When the South Busway opened in 1977 it was 4 miles long. The busway has two 14 foot travel lanes and curbs. The cost for construction was $27 million. An average of 15,000 passengers use the facility every day. The busway has reduced congestion on Route 51 which shares right of way with a light rail transit system. When compared to the old route on 51, the busway reduced the travel time by 15 minutes.

- The Martin Luther King East Busway was opened in 1983. It cost $113 million and stretches for 7 miles. This busway carries, on an average, 31,000 passengers per day. It was constructed in the right of way of an existing railroad line. This busway has reduced travel time by 20 to 30 minutes.

The United States is not alone in using dedicated bus/transit lanes. Canada uses them extensively throughout the country. 10 miles of the 13 mile long Ottawa transitway are reserved for buses only. It has one lane in each direction with shoulders on both sides. 7 out of 10 downtown workers regularly use the bus. The mode split is better than most North American cities and matches some European cities. The system carries 200,000 people per day. Ottawa has a "Transit First" policy that helps ensure land use around transit. Local feeder systems serve to move passengers in local areas and maintenance of service levels without the busway, would have required 145 additional buses.
• From 1972 to 1992 HOV lanes in Toronto meant bus-only lanes. At present time, there are 7 bus-only lanes in operation on arterial streets in the area. The east-west reserved bus lanes were implemented in 1971 to provide better access to major transit terminals. This project was very successful and is still in operation. In 1974, pilot bus lanes were opened on 5 streets to provide increased bus speed. These projects used curb lanes during peak periods. Two of these are in operation today. In 1982, a suburban arterial street was implemented. The Pie IX Boulevard is the first of two bus-only lanes in Montreal. The second is the Park Avenue facility. The Pie IX lane is located in the median because of concerns about turning accessibility and other issues. The buses have flashing yellow arrows on the front to warn motorists and pedestrians. The buses are also equipped with radios allowing the driver to communicate with the control center. This lane saves 10 minutes in travel time.

• Bus-only lanes are in operation on several arterial streets in Madrid, Spain. They were first implemented in the 1970's. The purpose of these lanes was to increase the operating speeds in the congested corridors. They use contra-flow, barrier-separated, and concurrent flow lanes. Results have been positive. The only problem faced was enforcement.

• Many developing countries are using bus-only lanes to reduce traffic. Taiwan has implemented contra-flow bus-only lanes on two major arterial streets. These have been in effect since 1989. These roads are parallel and connect the old downtown area with newly developed residential and businesses in the east. The Xin-Yi Road facility is used more. There are 16 bus routes that operate on the lane. There are 80 to 100 buses using the lane during the peak hour. There are no priority signals for the buses. Operating costs have reduced since implementation.
5.7 FREEWAY INCIDENT DETECTION AND MANAGEMENT SYSTEMS

5.7.1 Illinois Traffic Management

The freeway traffic surveillance and control system in northeastern Illinois has a centrally supervised, operational network of more than 130 miles, with 2,000 detectors, 95 ramp controls, and 13 changeable message signs (McDermott 1992). Remote terminals and sensors hooked up to the IDOT surveillance computer provide current traffic information, which is used to generate traffic reports for IDOT, public agencies, television and radio stations.

Program
The Traffic Systems Center (TSC) handles the Freeway Traffic Management (FTM) automatic surveillance, control, and information systems. The traffic management program in Illinois also includes emergency traffic control, a motorist assistance program and a highway advisory radio. The highway advisory radio stations broadcast traffic information from low-power roadside AM radio transmitters. A real-time automatic update mode is provided by having the surveillance sensors produce digitized voice broadcasts for each site.

Results
Reductions in congestion and accidents are important measures of effectiveness of a traffic congestion management program. Reductions of up to 60 percent in peak period traffic congestion and up to 18 percent in accidents have been measured in several comprehensive before and after studies of the FTM program elements (McDermott 1992). In a benefit to cost ratio study performed by Cambridge Systematics Inc. in Alexandria, Virginia, the incident management elements of the FTM program have been estimated to yield $17 in public benefits for every dollar spent by the Illinois Department of Transportation (IDOT) (1992).
Important Development

The single most important achievement of the FTM program has been the ongoing development of the system components that work together to reduce congestion, accidents, and incidents, while operating with the structured and traditionally organized state highway department framework. Additional developments include “Operation Greenlight,” the new multi-agency transportation planning process, which is being implemented to address urban and suburban traffic congestion issues in northeastern Illinois. IDOT, Motorola, the Federal Highway Administration, and the Illinois Universities Transportation Research Consortium are partners in the AdVANCE Project (Advanced Driver and Vehicle Advisory Navigation Concept). In this project, as many as 5,000 instrumented "probe" vehicles will be involved in a large scale dynamic route guidance operational test on a suburban road network (1992).

5.7.2 Seattle Area Incident Management

Program

The Seattle program utilizes and Traffic Safety Management Center (TSMC) to communicate freeway incidents to the general public by way of radio and variable message signs (1992). A highway worker is usually the first at an incident and are involved in the clean-up.

Objectives

The main objectives of the Washington State DOT's (WSDOT) Seattle incident response program are to respond to incidents in a timely manner, provide traffic control for the safe passage of motorists, and protect of emergency personnel at an incident scene (Berg 1992).

Results

With the formation of the incident response program, WSDOT's response time to an incident now averages 15 minutes. This means that traffic control is about 15 minutes after the incident response team is called. Once traffic control has been established, traffic is kept moving and
there are shorter back-ups. The program is also coordinated with the local media. WSDOT’s incident engineer estimates that this coordination has led to a one-to-two hour time savings in the clearing of an incident.

One of the concerns about the Seattle program is liability for moving vehicles and cargo from the roadway. Prior to the incident management response program, private towing companies responding to an incident at the request of the police bore all liability for property damage (Berg 1992). Often, these trucks were slow to respond to incidents. Because the state is removing vehicles, they are exposing themselves to potential tort actions.

5.7.3 Toronto Traffic Management

The newest traffic management system in Toronto is called COMPASS. COMPASS went into operation in early 1991 and covers nearly 16 kilometers of Highway 401, which is a main commuter route in the city. The Highway 401 COMPASS system employs three strategies:

- Detection and Confirmation;
- Incident Management;
- Motorist Advisory.

Detection and Confirmation

Detection is primarily accomplished through the use of more than 700 wire loop detectors embedded in the freeway pavement. Detector stations are located at approximately 500 meter intervals and transmit traffic data back to the district traffic operations center (Korpal 1992). A central computer at the operations center constantly analyzes the data using an incident detection algorithm. The goal is to detect most lane blocking incidents within three minutes of occurrence. Closed circuit television cameras provide the means of confirmation. The COMPASS system employs cameras with full pan, tilt, and zoom capabilities placed at 1000 meter intervals, effectively providing 100 percent coverage of the roadway.
Motorist Advisory

The COMPASS system utilizes 13 changeable message signs located upstream of strategic divergent points (1992). These message signs provide information to motorists and allow them to avoid a problem area. The light signs display three lines of text using low maintenance, light-emitting diode displays. The central computer recommends a specific set of signs and messages based on the location and nature of the incident. For incidents of longer duration, the Toronto system has portable information signs that may be located at strategic areas.

To aid in the dispersion of information about freeway conditions, the traffic center staff operates a traffic and road information system covering all provincial highways and freeways within the Toronto district. Traffic reports are sent by fax to the media on both a regular and an emergency basis.

Future Plans for the Toronto System

The following plans for the upgrade of the Toronto Incident Management System are planned or under way:

- The changeable message signs will be enhanced to include not just incident information but general traffic congestion information as well;
- Extension of the current Highway 401 COMPASS system are under design to include most of the freeway network in greater Toronto;
- The province is planning on using an AM band for updates for motorists; and
- There is the investigation of utilizing the cellular phone network in southern Ontario as a means of incident detection.

In addition to these upgrades, there is research into a new algorithm for congestion detection logic (CDL) known as the McMaster Algorithm (Forbes 1992). The McMaster Algorithm detects congestion by the observation of a low speed, a high occupancy, or "congested flow". The algorithm uses a persistence check to screen out spurious data points (1992). Operations
are considered congested if the speed is below the uncongested threshold, or the flow is congested for three consecutive 30-second intervals. Testing of this algorithm was completed using data gathered from the Queen Elizabeth Way Freeway Traffic Management System (QEW FTMS) in Ontario, Canada. Each detector station in the QEW FTMS consists of paired induction loops, 6 meters apart (1992). Station spacing is 800 m.

5.7.4 Operation of Traffic Management Systems In The U.S.

In general, the freeway management systems that have been built over the past 35 years have demonstrated their ability to achieve significant benefits. The initial small experimental systems were prone to failure due to faulty equipment and a lack of existing techniques from which to draw experience. From these early beginnings, a number of freeway management systems have developed, becoming very extensive and sophisticated.

A summary of the majority of the freeway management systems in North America was given in Table 4.3 (refer chapter 4). As can be seen in the table, the type and functions of the systems are extremely variable. Many of the smaller systems have no central electronic surveillance and no variable message signs, but rely on ramp control only. By contrast the New Jersey Turnpike system has no ramp control, but 136 variable message signs that give information on the conditions on the freeway and, in certain locations, advise drivers on alternative routes. Differing strategies are obviously required to suit the needs of individual freeways. By careful planning and the use of evaluation exercises, freeway management systems can slowly grow to meet the specific needs of cities. The following gives a brief summary of some systems in operation in the United States.

Chicago

In 1961 a project was started in Chicago to improve traffic network flow by means of automatic control and information techniques. The initial efforts involved the installation
of 25 detectors on a 5-mile section of the Eisenhower Expressway. These detectors provided basic traffic flow information. From the beginning, the system has grown to the point where, in 1982, 220 directional miles of freeway are under control, there are 1,700 loop detectors, and 70 metered ramps. The system handles approximately 14 million vehicle-miles of travel per day, and its service patrols, on an average day, assist more than 200 disabled motorists.

**Northern Virginia**

In Northern Virginia, about 200,000 vehicles use the I-395 and I-66 corridors daily. The VDOT has developed a comprehensive traffic management system to reduce congestion on these two major interstates. The TMS system plays a significant role in reducing the time it takes to detect and remove an incident and vehicles from the interstate system. The TMS gathers traffic data in the form of vehicle volume and speed by using 550 traffic loops embedded in the traffic lanes and entrance ramps. Thirty-eight closed circuit television cameras (CCTV) placed at key locations along the two interstates allow traffic managers to monitor traffic inside the control center for traffic congestion, accidents, and disabled vehicles. If an accident occurs within the range of the cameras, the control center has the capability to zoom in with the camera to get a close-up view of the situation. There are 72 changeable message signs that can be changed by remote control to display a variety of messages to motorists. A State Police area headquarters is also located in the building for quick response to accidents, traffic delays, and other incidents.

**5.7.5 Operation of Traffic Management Systems Abroad**

In the middle to late 1980's the Europeans and the Japanese were regarded as the world leaders in intelligent vehicle -highway systems. The European reputation was based upon two major programs that had attracted worldwide attention because of their financial expenditures and level of effort. Those programs were PROMETHEUS (PROgraMme
for European Traffic with Highest Efficiency and Unprecedented Safety) and DRIVE (Dedicated Road Infrastructure for Vehicle safety in Europe).

**Great Britain**
Freeway surveillance and control centers existed in four countries. In many respects, these freeway management systems are very similar to those in North America. In Britain, four separate motorway control centers monitor the 119 mile long M-25 - the orbital beltway that surrounds London. Television monitors, a wall map, and a variety of communications made one of these centers appear very much like a North American Facility. This center, which monitored about one-fourth of the M-25, had 17 television cameras deployed in the field with 16 more to be installed in 1992. Detector loops are located at 1/2 kilometer intervals in the roadway, and motorists call boxes at one kilometer intervals. The entire freeway system in Britain has communications lines installed; although much of the communications is still copper wire, it is being replaced by fiber optic cable. Fiber optics is used to transmit television pictures from the field to the control centers. Unlike the United States, where centers are operated by the highway agency, the British Motorway Control Centers are operated by the police.

**The Netherlands**
Amsterdam's freeway control center is very modern, having become operational within the past two years. Television cameras monitor traffic conditions in the field. Computer graphics displays are used to present information on traffic conditions and the status of changeable message signs. A feature of the Dutch freeway control which is unlike anything in North America is the Motorway Control and Signaling System. One hundred and fifty kilometers of Dutch motorways have small variable message signs placed on overhead sign bridges at 3/4 kilometer intervals. Each lane has a small variable message sign placed above it which can display it a regulatory speed limit (50, 70, or 90 kilometers per hour), a yellow arrow symbol (meaning that a lane should be vacated), a red X symbol (meaning
that a lane is closed), or a symbolic legend indicating that there congestion ahead. The Dutch claim that lane changing is reduced, secondary accidents are reduced by 50 percent, total accidents are reduced by 24 percent, delay is reduced by 15 percent, and a 3 to 5 percent increase in throughput is achieved. The symbolic yellow arrows and red X’s are very useful when maintenance operations require lane closure.

Germany
The Germans have a control and signaling system very similar to the Dutch. Overhead variable signs can present 100, 80, and 60 kilometer per hour messages. In addition, a variable message sign on each side of the roadway (on the sign bridge supports) also presents information, such as a symbolic message indicating road work ahead. An unusual system of changeable message destination signing is used on the autobahn. German overhead guide signs appear very much like those in North America, except that the background is blue instead of green. However, rotating drums provide the ability to change the destination name(s) shown on the sign. If two autobahn routes lead to a geographic destination, and the usual route suffers an incident, the signs can change to show the secondary route as the route to follow to reach the destination. Many of the 16 German states have an autobahn traffic control center and most states will have one in the future.

Japan
Reports have been received from Japan on 388 miles of rural freeway and on 91 miles of urban freeway. All freeways are equipped with variable message signs to deal with emergencies. Unlike the British system where the decision has been made to tell the driver only what action to take, the conciseness of the Japanese written language makes it possible to tell drivers both what action to take and the reasons for it being necessary. Control of traffic on the rural freeways is exercised by means of variable-message signs. Information is obtained from the emergency telephones, from radio patrol cars, from toll
areas, from closed circuit television cameras installed on long tunnels, and from vehicle detectors.

5.8 HOV LANES

Many of the HOV applications have been attempts at relatively low cost methods for increasing the capacity of overcrowded freeways. This is especially true of some of the early facilities, which may have been implemented as part of Transportation System Management (TSM) programs. Approaches utilized in these cases include restriping to add an HOV lane to an existing facility, utilizing the shoulder for an HOV lane, and other relatively low cost treatments. Other HOV facilities represent permanent, long-term improvements. These include the construction of higher cost projects, such as bus-only facilities on separate rights-of-way and exclusive HOV facilities on freeways. There are quite a number of examples of successful installations of HOV facilities in the United States. Several of these will be discussed briefly.

5.8.1 Houston Transitway System

In the early 1970’s, the Houston area was experiencing growth and traffic trends that were creating some of the congested freeways in the nation. Recognizing the economic and physical impossibility of providing enough highway capacity to serve the demand, local officials developed a scheme to implement a system of preferential lanes for HOV’s on the freeways. Locally these lanes are referred to as “Transitways”, because they were initially made available to buses and authorized vanpools only. Over time, to improve utilization and efficiency, the operating rules have been modified to allow selective use of the lanes by carpools as well.
Program

At the end of 1989, 36.6 miles of Transitways were in operation, involving segments of four different freeways. These include:

- The North (I-45N) Transitway, opened in 1984;
- The Katy (I-10) Transitway, also opened in 1984;
- The Gulf (I-45), opened in 1989; and
- The Northwest (US 290), also opened in 1989.

All these are radial to the Houston Central Business District (CBD) and are part of what is ultimately planned to be a 95.5 mile system. Physically, this system has some segments of two-way highway, but the typical installation is a separate, one-way facility located in the freeway median, approximately 20ft wide, reversible, and separated from the mixed-use freeway lanes by concrete barriers.

Results

The initial priority lanes (I-45N and I-10) were opened as transit and vanpool facilities only, but subsequently opened to carpools as well. The travel time savings on these older facilities averages 5 to 14 minutes and 2 to 3 minutes on the newer facilities. Users, however, perceive the travel time savings to be 10 to 20 minutes. The impact of these real perceived savings is demonstrable: Transit ridership and carpooling has essentially doubled in the older (I-45N and I-10) corridors. The impact of these HOV facilities as a transportation management strategy is reflected in the Table 5.8.
Table 5.8: Transit/Carpooling Ridership in HOV Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Pre-transitway Vehicle Trip Rate</th>
<th>With HOV Vehicle Trip Rate</th>
<th>Percent Reduction Using Freeway</th>
</tr>
</thead>
<tbody>
<tr>
<td>North (I-45N)</td>
<td>98</td>
<td>60</td>
<td>23%</td>
</tr>
<tr>
<td>Katy (I-10)</td>
<td>79</td>
<td>68</td>
<td>14%</td>
</tr>
<tr>
<td>Northwest (I-45)</td>
<td>88</td>
<td>76</td>
<td>14%</td>
</tr>
<tr>
<td>Gulf (US 290)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: Vehicle Trips Rate = No. of vehicle trips required to transport 100 travelers
(Source: Implementing Effective Travel Demand Management Measures, USDOT, 1993)

As indicated in the table above, the carrying efficiency of each of the facilities before and after implementation of the HOV lanes shows much improvement. This is expressed in terms of the number of vehicle trips it would require to transport each 100 travelers in the peak direction during peak hour. Installation of the transitway on I-45N produced results that can be interpreted as a 23% reduction in vehicle trip demand on the freeway as a result of the transitway, or a 23% improvement in the ability to transport people on the freeway. As shown the Katy and Northwest Transitways show 14% decreases in vehicle demand.

5.8.2 I-394 Interim HOV Lane

Interstate 394 is the major link in the Minneapolis transportation system, connecting the western suburbs and the circumferential freeway, I-494, with downtown Minneapolis. I-394 was created by converting then existing Trunk Highway (TH) 12, a 4-lane arterial with numerous access points and signalized intersections, to an Interstate Highway.

Program

The Minnesota DOT constructed a barrier separated, two lane reversible HOV facility in the median of I-394. The facility is 3 miles in length. The final design for the project also
included eight miles of concurrent flow HOV lanes. Objectives for the project were listed at its outset. These included:

- Increase the ride share and transit modal split;
- Improve the level of service for all traffic on I-394;
- Improve accident rates;
- Achieve a low HOV violation rate.

Results

The Minnesota DOT commissioned a before and after study to evaluate the effectiveness of the HOV facility. The existing conditions and expected impacts of the HOV facility are presented in Table 5.9. The HOV facility is expected to increase by two and one half times the number of car and vanpools on the highway, and increase the average auto occupancy rate on I-394 from 1.23 persons per vehicle to 1.6 persons per vehicle, once the facility reaches a point of stable operation.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase the Auto Peak Hour Modal Split</td>
<td>Carpools/Vanpools</td>
<td>625</td>
<td>700</td>
<td>1,075</td>
<td>1,585</td>
</tr>
<tr>
<td></td>
<td>Carpool/Vanpool/ Occupants</td>
<td>1,380</td>
<td>1,540</td>
<td>2,515</td>
<td>4,900</td>
</tr>
<tr>
<td></td>
<td>Carpools as % of Autos</td>
<td>19%</td>
<td>21%</td>
<td>25%</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>Carpool Occupants as % of Auto Occupants</td>
<td>34%</td>
<td>36%</td>
<td>42%</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>Auto Occupancy Rate</td>
<td>1.23</td>
<td>1.25</td>
<td>1.3</td>
<td>1.6</td>
</tr>
</tbody>
</table>

(Source: Implementing Effective Travel Demand Management Measures, USDOT, 1993)

Additionally, two more important Transportation system changes occurred as a result of the introduction of the interim HOV lane:

- First, travelers did respond to the signals posed by the lane by switching travel mode. The percentage of peak period travelers driving alone dropped from 61.9 percent to 48.7 percent, with a significant increase in the rate of ridesharing from 20.2% to 32.85. This produced an increase in average vehicle occupancy from 1.17 to 1.29.
- Second, because of its improved efficiency, the modified TH 12 attracted travelers from parallel roadways to the north and south, resulting in a 35.4% increase in total persons using the highway, while total vehicle trips increased by only 22.6%. These reflect significant transportation management impacts.

### 5.8.3 Shirley Highway Busway

The Shirley Busway on I-395 through Northern Virginia into Washington, D.C. has been in operation for over 20 years. The Busway shows how a well designed and located HOV facility can give outstanding transportation service even as conditions change over time.
Opened as an exclusive busway during massive freeway reconstruction, it was later opened to carpools and vanpools with four or more occupants. Now it complements and feeds into more recent Metro rapid transit service and is open to pools with three or more occupants.

Program
Shirley Highway serves a congested commuter corridor into downtown Washington and Arlington employment areas. The Busway is a 11 mile, two-lane reversible facility in the center of I-395. It operates in the peak direction of traffic flow, inbound in the morning and outbound in the evening, using sophisticated signing and ramp controls. There are no on-line stations, but exclusive ramps give access to key locations including the Pentagon, and its Metrorail station

Results
- The present 11-mile Shirley Busway served only buses from partial opening in 1969 until van and carpools were admitted in 1974. By the end of construction, buses and carpools were saving 19 minutes over mixed traffic during peak morning flow.
- Vehicles per person were reduced by 16 percent after introduction of car and vanpools in 1974.
- 12 minutes of HOV facility time savings is attained by ridesharing
- HOV parking incentives at the worksite are on average worth eight minutes of HOV facility time savings.
Table 5.10 gives the traffic impacts of various HOV lanes already implemented.

<table>
<thead>
<tr>
<th>Facility</th>
<th>1988 Morning Peak Hour Peak Direction Ridership</th>
<th>Vehicles/Person Trip Reduction During Introductory Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bus</td>
<td>Vanpool/ Carpool</td>
</tr>
<tr>
<td>I-495 NJ/NY</td>
<td>34,685</td>
<td>0</td>
</tr>
<tr>
<td>I-395 VA/DC Shirley Hwy.</td>
<td>5,621</td>
<td>9,483</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>El Monte - L.A I-10</td>
<td>2,750</td>
<td>4,352</td>
</tr>
<tr>
<td>I-10 Katy, Houston</td>
<td>1,820</td>
<td>2,595</td>
</tr>
<tr>
<td>US 290 Northwest, Houston</td>
<td>2,810</td>
<td>416</td>
</tr>
<tr>
<td>I-45N, Houston</td>
<td>2,810</td>
<td>416</td>
</tr>
<tr>
<td>I-95 Miami (g)</td>
<td>350</td>
<td>2,460</td>
</tr>
<tr>
<td>Minneapolis I-394 (Interim)</td>
<td>455</td>
<td>942</td>
</tr>
</tbody>
</table>

Notes:

(a) A pre-existing decline in transit ridership was arrested.
(b) First full year of operation through bus-only phase
(c) First full year of operation through initial operation with van and car pools allowed
(d) Freeways only (no arterials data included)
(e) From first partial opening to van and car pools through full opening to van and car pools
   (does not include impact of original opening to buses)
(f) Representative current value compared to representative pre-transitway value, less the
   vehicles/person trip reduction observed on freeway without transitway.
(g) 1985 data

(Source: Implementing Effective Travel Demand Management Measures, USDOT, 1993)

5.9 Future Technologies

IVHS is a relatively new concept in the transportation field. Consequently, a review was performed on Smart Highways by the General Accounting Office of the United States Government in 1991. An analysis of 38 reports demonstrated a strong consensus for implementation of IVHS technology, particularly in the area of congestion reduction. It was also realized that economic benefits, safety improvements, reduced fuel consumption,
and air quality improvements are also possible in some cases. The magnitude of projected transportation benefits varies widely, depending upon numerous factors such as the type of IVHS technology and the level of existing traffic congestion. In the following, we will briefly discuss the three important divisions of IVHS associated with reducing congestion, Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), and Advanced Vehicle Control Systems (AVCS).

5.9.1 ATMS

While certain ATMS technologies have been deployed in the United States and overseas, reported results of field tests are scarce and pertain primarily to the more current technologies, such as traffic signal control equipment and freeway surveillance and control techniques. We have discussed some of these traffic management systems earlier in this chapter, and Table 5.11 gives a brief description of the benefits associated with the four projects. As learned earlier, three of the studies looked at traffic signal control systems and addressed the effectiveness of computer programs and related technologies.

To estimate the effects of future ATMS systems, 7 studies employed computer modeling and mathematical analysis techniques. For example, one study evaluated the probable effects of an advanced traffic management system on a heavily traveled corridor in California. The study reported potential travel time reductions of 11 to 15 percent, intersection delays of nearly 2 million vehicle hours per year, and vehicle stop reductions of approximately 35 percent per year.

Each study reported positive effects on congestion reductions in travel time and delays of between 10 and 50 percent, increases in average speed of between 29 and 35 percent, and increases of capacity of between 12 and 40 percent.
<table>
<thead>
<tr>
<th>Name of Study</th>
<th>Author</th>
<th>Study Date</th>
<th>Evaluation and Methodology</th>
<th>Technology Demonstrated</th>
<th>Reported Benefit</th>
</tr>
</thead>
</table>
| National Signal Timing Optimization Project (11 cities nationwide)            | FHWA            | 1982       | Before-after; simulation model | ATMS, improving traffic signal timing plans | For each average intersection:  
  • 15,000 vehicle hours of delay saved  
  • 455,000 vehicle stops eliminated  
  • 10,000 gallons of fuel saved  
  • $28,695 average annual benefit  
  • 8.5% improvement in travel time  
  • B/C ratio of 63:1                                                              |
| Fuel-Efficient Traffic Signal Management (FETSIM) (61 cities and 1 county in Calif.) | ITS             | 1986       | Before-after; simulation model; field test | ATMS, improving traffic signal timing plans | • 15% reduction in vehicle delays  
  • 16% reduction in vehicle stops  
  • 7% reduction in travel times  
  • 8.65 reduction in fuel use  
  • $231 million savings over 3 years  
  • B/C ratio of 58:1                                                              |
| Automated Traffic surveillance and Control (ATSAC) (Los Angeles, California) | LA Dept. of Transp. | 1987       | Before-after | ATMS, computer control of traffic signals | • 13% reduction in travel time  
  • 35% reduction in vehicle stops  
  • 14% increase in average speeds  
  • 20% decrease in intersection delay  
  • 12.55 decrease in fuel consumption  
  • B/C ratio of 9.8:1                                                              |
| Chicago Area Expressway Surveillance and Control project (Chicago, III)       | McDermott et al. | 1979       | Before-after | ATMS, large-scale freeway surveillance and control system | • 30% reduction in peak period congestion  
  • 18% reduction in accidents  
  • Decreased travel times and increased average speeds  
  • B/C ratio of 4:1 (ramp metering)                                              |

(Source: United States General Accounting Office: Smart Highways, 1991.)
5.9.2 ATIS

ATIS technologies build upon ATMS in providing route guidance and real-time information to commuters. These technologies are not as developed as ATMS, and consequently, there are no completed domestic field experiments. Eleven reports addressed the congestion-related effects of ATIS using analytical methodologies. These studies examined the potential effectiveness of various technologies that could provide the traveler with route guidance and real-time traffic information. Different ATIS configurations were represented in the analyses, such as whether travelers received their information before or after their route or whether the ATIS system provided just traffic information or provided route guidance as well. Depending on the testing circumstances and the ATIS configurations tested, these reports showed possible reductions in travel time ranging from 2 to 50 percent with a concomitant range in congestion reduction.

While ATIS systems are very recent in the United States, these systems have been studied more extensively in Europe and Japan. For example, an early study of a Japanese real-time route guidance system showed average travel time savings of 11 percent, and a later analysis in Tokyo showed that travel time savings between 9 and 14 percent could be realized in urban settings.
<table>
<thead>
<tr>
<th>Name of Study</th>
<th>Author</th>
<th>Study Date</th>
<th>Estimated Benefit</th>
</tr>
</thead>
</table>
| Smart Corridor for the City of Los Angeles: Demonstration Project Conceptual Design | JHK & Associates      | 1989       | **Overall Corridor Effects:**  
  • Travel time reduction by 11-15%  
  • Intersection delay reduced by 20%  
  • Annual savings of $24-32.5 million  
  • Fuel consumption reduced by 2.5%/year  
**Individual Driver Effects:**  
  • Increased average speeds during peak commute periods by 11%  
  • Increased average freeway speeds from 35mph to 50mph  
  • Decreased average surface street trip duration by 13% |
| Potential Benefits of In-Vehicle Information Systems in a Real Life Freeway Corridor Under Recurring and Incident-Induced Congestion | Al-Deek et al.           | 1988       | Travel time savings between 3-10 minutes per freeway trip during nonrecurring, incident-induced congestion.                                    |
| Potential Benefits of In-Vehicle Information Systems: Demand and Incident Sensitivity Analysis | Al Deek & May         | 1988       | Travel time savings ranging 0-14 minutes (0-47%) for a 30 minute average trip under different congestion scenarios.                              |
| Some Theoretical Aspects of the Benefits of En-Route Vehicle Guidance (ERVG) | Al-Deek & Kanafani    | 1990       | Typical Travel time savings of 3.4%.                                                                                                             |
| Effectiveness of Motorist Information Systems in Reducing Traffic Congestion  | Koutaopoulos & Lotan  | 1989       | Modest reduction in travel times up to 4.4%.                                                                                                     |
| Study to Show the Benefits of Autoguide in London                           | JMP Consultants       | 1989       | • Resource cost savings of 7.9%  
  • Travel time savings of 8-11%                                                                                                                   |

(Source: United States General Accounting Office: Smart Highways, 1991)

5.9.3 AVCS

Although a majority of the studies that were researched involved either ATMS or ATIS, there were 9 studies evaluated to determine the performance of AVCS systems in reducing congestion. These describe how automated freeways could substantially increase highway
capacity by allowing vehicles to travel closer together at higher speeds. Further, the computer control aspects of this system are intended to eliminate traffic flow problems associated with accidents, poor drivers, or bad weather.

Because of the long range nature of automated highway freeways, no field based assessments of their potential could be investigated. However, a study performed in 1982 by General Motors on freeway capacity improvements using automated highway technologies, provided results which were beneficial to alleviating congestion. The study analyzed capacity improvements for three different average speed scenarios (40, 50, and 55 mph). The analysis estimated between a 27 percent and a 103 percent improvement in highway capacity, with the latter representing a more full-scale AVCS development scenario. Beyond such simulations of automated highway potential, most of the discussion of AVCS has been based on transportation experts’ knowledge of the individual technologies that constitute this system and their estimates of possible effects. In general, it is believed that AVCS may effectively increase highway capacity by up to 300 percent without widening the existing highway or building new ones.

To conclude this chapter, a brief overview of the current operational tests in advanced technologies will be reviewed. Table 5.13 gives nine federal operational test projects that are currently investigating IVHS applications. Though none of these projects are complete, they display several characteristics and suggest areas of emphasis where federal involvement may be beneficial. Most of the projects examine congestion reduction effects, improved air quality, and reduced fuel consumption.
### Table 5.13: Operational Tests Overview

<table>
<thead>
<tr>
<th>Project</th>
<th>Current Funding</th>
<th>IVHS Component</th>
<th>Demonstration Focus</th>
<th>Expected Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATH (Berkeley, Calif..)</td>
<td>$9.4 million</td>
<td>ATIS</td>
<td>• Automated Freeways</td>
<td>• Reduced Congestion.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AVCS ATMS</td>
<td>• Electrification</td>
<td>• Reduced Air Pollution.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Navigation</td>
<td>• Improved Safety.</td>
</tr>
<tr>
<td>Pathfinder (Los Angeles, Calif)</td>
<td>$2.5 million</td>
<td>ATIS</td>
<td>• In-vehicle navigation systems</td>
<td>• Reduced congestion</td>
</tr>
<tr>
<td>TRANSCOM (Jersey City, N.J.)</td>
<td>$3 million</td>
<td>ATMS ATIS</td>
<td>• Incident Management</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Automatic Vehicle Identification</td>
<td></td>
</tr>
<tr>
<td>TRAVTEK (Orlando, Florida)</td>
<td>$8 million</td>
<td>ATIS</td>
<td>• In-vehicle Navigation Systems</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Traveler Information</td>
<td>• Reduced Air Pollution.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Reduced Fuel Consumption</td>
</tr>
<tr>
<td>INFORM (New York, N.Y.)</td>
<td>$30 million</td>
<td>ATMS</td>
<td>• Integrated Systems</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Freeway Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Variable Message Signs</td>
<td></td>
</tr>
<tr>
<td>Incident Management (Minneapolis-St. Paul, Minn.)</td>
<td>$458,300</td>
<td>ATMS</td>
<td>• Traffic Information</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Incident Response</td>
<td>• Improved Safety.</td>
</tr>
<tr>
<td>Incident Management (Seattle, Wash.)</td>
<td>$150,000</td>
<td>ATMS</td>
<td>• Incident Response</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Improved Cooperation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Improved Public Perception</td>
</tr>
<tr>
<td>Arterial Control &amp; Integration (Seattle, Wash.)</td>
<td>$130,000</td>
<td>ATMS</td>
<td>• Integrated Systems</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Demonstrate low-cost systems integration</td>
</tr>
<tr>
<td>Urban Congestion Alleviation Project (Washington, D.C.)</td>
<td>$1.16 million</td>
<td>ATMS</td>
<td>• Video Detection</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Traffic Advisory Radio</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Variable Message Signs</td>
<td></td>
</tr>
<tr>
<td>Anaheim Integrated System Project (Anaheim, Calif.)</td>
<td>$2.1 million</td>
<td>ATMS ATIS</td>
<td>• Events Management</td>
<td>• Reduced Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Institutional Coordination</td>
<td>• Related Motorist and fuel savings</td>
</tr>
</tbody>
</table>

(Source: United States General Accounting Office: Smart Highways, 1991)
6.0 CONCLUSIONS

It is obvious that urban and suburban highway congestion is the result of many factors. Many of these factors are intermittent as discussed in the earlier chapters, and they continue to contribute to intensify the congestion problem. The main causes can be attributed to these specific recurring conditions: 1) more people traveling in metropolitan areas; 2) more people traveling by their own car instead of using mass transit; 3) more people traveling to and from the location dispersed throughout the region; and 4) more people traveling in areas where the necessary highway capacity has not been provided. These are trends that are being experienced all over the country and have generated travel demands that are exceeding not only the supply that is available at a reasonable level of service, but the very capacity of the transportation system itself.

The following summarizes the supply management tools discussed earlier for urban freeways and non-freeways. This conclusion further emphasizes the importance of the application of these low-cost measures for alleviating congestion in urban areas.

6.1 Supply Management Tools for Urban Freeways and Non-Freeways

Table 6.1 gives the important characteristics of the tools described in Chapter 4. The use of supply side strategies, whether TSM improvements or freeway management systems, can be used to provide flexible cost-effective approaches to reduce a significant portion of freeway urban congestion. Similar benefits can be obtained from measures reducing nonfreeway congestion. Measures, like traffic signal improvements, are very efficient in reducing vehicle delay.
<table>
<thead>
<tr>
<th>Supply Measure</th>
<th>Impact</th>
<th>Cost</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Control Devices</td>
<td>High B/C ratios; substantial benefits in channelizing traffic</td>
<td>Minimal</td>
<td>• Devices should be of proper standards</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Long-term maintenance strategy</td>
</tr>
<tr>
<td>Improved Intersections</td>
<td>Varies by level of improvement</td>
<td>Modest to Minimal</td>
<td>Need to follow engineering principles</td>
</tr>
<tr>
<td>Improved Signals</td>
<td>• 8-25% improvement in travel time</td>
<td>Low, approximately $3000/signal update</td>
<td>Strong traffic engineering expertise</td>
</tr>
<tr>
<td>(Computerized)</td>
<td>• 10-30% improvement in vehicle speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp Metering</td>
<td>• Increase in speeds by 29%</td>
<td>Low to moderate cost, $50,000/unit</td>
<td>Long time frame to implement; more suited for suburbs</td>
</tr>
<tr>
<td></td>
<td>• With delays included, speed increases of 20% and travel time by 16.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reduction in accidents by 20-38%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increase in freeway volumes of 20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street Widening</td>
<td>Increased Capacity Possible</td>
<td>Modest</td>
<td>May not be applicable to most areas due to scarcity of land</td>
</tr>
<tr>
<td>Add Lanes without widening</td>
<td>Increase in capacity: B/C ratios of 7:1</td>
<td>About 1.3 million/mile for design and construction and $12,000/yr for maintenance</td>
<td>Proper cooperation and coordination between highway agencies and traffic enforcement required</td>
</tr>
<tr>
<td>New Highways</td>
<td>• Significant increases of capacity</td>
<td>Costs vary from 4.5 million/lane-mile for freeway and $1.5 million/lane-mile for an arterial</td>
<td>• Funding is a key issue</td>
</tr>
<tr>
<td></td>
<td>• New development and reduction in accidents</td>
<td></td>
<td>• Careful consideration should be taken to ensure new construction does not lead to be a new source of congestion</td>
</tr>
<tr>
<td>One-Way Streets</td>
<td>• Increase capacity from 20-50%</td>
<td>Minimal, approximately $27,000/mile</td>
<td>• Public outreach required</td>
</tr>
<tr>
<td></td>
<td>• Reduction in travel time from 20-40%</td>
<td></td>
<td>• Parallel Streets with suitable capacity should be made available</td>
</tr>
<tr>
<td></td>
<td>• Reduction in accidents by 60%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSIONS
<table>
<thead>
<tr>
<th>Supply Measure</th>
<th>Impact</th>
<th>Cost</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversible Traffic Lanes</td>
<td>• Reduction in travel times from 10-25%</td>
<td>Minimal, although operating costs are required</td>
<td>Enforcement agencies need to be involved in the planning and operation stages</td>
</tr>
<tr>
<td></td>
<td>• Capacity Increases of 20-50% possible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn Prohibitions</td>
<td>• Capacity Increases of 14-40%</td>
<td>Minimal</td>
<td>Feasibility of alternate solutions should be identified</td>
</tr>
<tr>
<td></td>
<td>• Travel time reductions of 35-70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Accident reductions of 40-70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super Street Arterials</td>
<td>• Capacity increases of 50-70% possible</td>
<td>Very expensive, about $4-5 million/mile</td>
<td>• Long time frame</td>
</tr>
<tr>
<td></td>
<td>• Decrease of 20% in accidents</td>
<td></td>
<td>• Highly disciplined policy to ensure maintenance of features</td>
</tr>
<tr>
<td>Arterial Surveillance and</td>
<td>• Increase in vehicle capacity of 30%</td>
<td>Cost lies between $0.5 million-to 1 million/lane-mile</td>
<td>• Funding and coordination are key issues</td>
</tr>
<tr>
<td>Control</td>
<td>• B/C ratios of 12:1 possible</td>
<td></td>
<td>• Multiagency effort required</td>
</tr>
<tr>
<td>Motorist Information Systems</td>
<td>Significant reductions in delay on specific facilities</td>
<td>Can be low-cost</td>
<td>• Long time-frame</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Ideally should be part of area-wide freeway management program</td>
</tr>
<tr>
<td>Freeway Incident Management</td>
<td>• Reduces detection time by 10 minutes</td>
<td>$1 million to design; $100,000 for maintenance</td>
<td>• Long time-frame</td>
</tr>
<tr>
<td>Systems</td>
<td>• Increases vehicle speeds by 20%</td>
<td></td>
<td>• of 5-10 years</td>
</tr>
<tr>
<td></td>
<td>• Overall congestion reduction by 30%</td>
<td></td>
<td>• Needs proper coordination between organizations</td>
</tr>
<tr>
<td></td>
<td>• B/C ratio of 4:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusive Bus Lanes</td>
<td>• Increased speed</td>
<td>For a new lane approximately $1.5 million/mile</td>
<td>Land use, density conditions, urban forms etc. are some issues</td>
</tr>
<tr>
<td></td>
<td>• Very flexible form of mass transit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOV Lanes</td>
<td>• 5 to 10% increase in peak hour/lane efficiency</td>
<td>Varies by type-</td>
<td>• Extensive planning required</td>
</tr>
<tr>
<td></td>
<td>• Reduced vehicle miles traveled by 5%</td>
<td>Ranges from 0.5 to $5 million/lane-mile</td>
<td>• Multi-agency cooperation and coordination necessary</td>
</tr>
<tr>
<td>Future Technologies</td>
<td>• Reduced Congestion</td>
<td>Very expensive based on technology applied</td>
<td>• Funding is a key issue</td>
</tr>
<tr>
<td></td>
<td>• Increased Safety</td>
<td></td>
<td>• Should evaluate B/C ratios for various technologies before implementation</td>
</tr>
<tr>
<td></td>
<td>• Decreased Vehicle emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Decreased fuel consumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Even the no-cost measure of signal removal has given significant benefits, (e.g. The cost of removing a signal is actually offset by the elimination of signal maintenance which yields, in effect, no cost).

In particular, low-cost improvements are shown to be very efficient. This can be attributed primarily to the targeting of low-cost improvements to specific problem locations or geometric bottlenecks. Overall, each measure is shown to be extremely cost-effective, as illustrated by the results in Table 6.1 It is important to realize that a balanced approach will produce even greater benefits. One of the key issues facing local officials and transportation professionals is combining the congestion reduction actions into overall strategies or programs when the congestion problems facing a community or region may require such an approach.

Regardless of whether the measures are operations oriented or for facility expansion, no one measure or single type of measure can effectively alleviate congestion alone. The results point to the fact that even an aggressive traffic management program will not be enough to do the job. A combination of supply measures may reduce 20% of the vehicle delay, and demand management may reduce a slightly greater amount. The need is clearly evident for new and expanded facilities to balance the operational improvements. It is also evident that IVHS is a potential solution in reducing congestion. Components like ATMS, AVCS and ATIS have a lot of expected benefits in alleviating congestion to great extents. Also for example, with the implementation of AVCS technologies a substantial increase would be established in capacity due to increase in the number of vehicles using the freeway at a particular time. Unfortunately, it is not expected that new construction or major reconstruction will completely reduce the remaining delay. Therefore, urban congestion and consequent vehicle delay will still exist in 2005, but the extent to which this effects travelers could be reduced with effective implementation of these measures.
6.2 Summary

With an overview of the various supply measures and a review of their effectiveness, we will briefly summarize the issue of congestion reduction and some implementation obstacles which have to be considered during the application of these strategies.

The actual reduction of congestion and vehicle delay can draw upon a wide array of strategies and measures designed for different aspects of the problem. These measures can be classified into five basic categories: supply management using TSM, additional capacity provided by new construction, highway reconstruction, demand management using both TSM and TDM, and, finally, advanced technologies. It is important to recognize the following:

- No single strategy can effectively reduce all aspects of congestion;
- A balanced approach of supply strategies (protecting and expanding capacity) and demand strategies (reducing the need to travel and modifying the time of travel) must be used to effectively reduce congestion;
- TSM supply measures (low-cost improvements, freeway and incident management, lane widening, signal improvements, ramp metering) are very cost-effective and efficient in relieving recurring and non-recurring congestion; and
- Advanced Technologies such as IVHS will be effective tools in alleviating congestion in the future.
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