STRATEGIC PLAN

Intelligent Vehicle-Highway Systems

Denver Metro Area

Project IVH-MP 9108(1)

for the
COLORADO DEPARTMENT
OF TRANSPORTATION

C-STAR

October 1992

by:
CENTENNIAL ENGINEERING, INC.
CASTLE ROCK CONSULTANTS
BALLOFFET AND ASSOCIATES, INC.

DOT/FHWA

IVHS Study for the Denver Metro Area

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LIST OF ACRONYMS/ABBREVIATIONS

APTS	Advanced Public Transportation Systems
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
AVCS	Advanced Vehicle Control Systems
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CIMC	Colorado Incident Management Coalition
CSP	Colorado State Patrol
CTI	Colorado Transportation Institute
c v o	Commercial Vehicle Operations
DAB	Digital Audio Broadcasting
DRCOG	Denver Regional Council of Governments
EON	Enhanced Other Networks
FHWA	Federal Highway Administration
FMCS	Fleet Management and Control Systems
FTA	Federal Transit Administration
GPS	Global Positioning System
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IVHS	Intelligent Vehicle Highway Systems
MAC	Metro Area Connection (Light Rail)
MOVA	Modernized Optimized Vehicle Actuation
OPAC	Optimized Policies for Adaptive Control
RDS	Radio Data System
RTD	Regional Transportation District
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split, Cycle, and Offset Optimization Technique
TMC	Traffic Message Channel
TOC	Traffic Operations Center
TP/TA	Traffic Program/Traffic Announcement
TSM	Transportation Systems Management
VMS	Variable Message Signs
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

Congestion costs the United States an estimated $100 billion annually. Traffic accidents - many caused by congestion itself - drain away another $70 billion per year. Inefficient movement of traffic reduces productivity, wastes energy, and increases emissions as each year, vehicles idling in traffic waste billions of gallons of fuel and needlessly emit tons of pollutants. At the same time, it has been internationally recognized that new pavement construction is no longer in itself a complete solution to addressing transportation needs, in some cases creating unacceptable impacts in meeting existing and future travel demands.

There is no simple answer to the set of complex transportation problems that confront us, but a group of technologies known as Intelligent Vehicle-Highway Systems (IVHS) can help enormously. In the past decade, advancements in computers, micro-electronics, satellite technologies, and the emergence of cellular telephones have changed the way we think and communicate. IVHS unites these technologies and others with our transportation system to save lives, save time, and save money.

IVHS comprises advanced transportation technologies in two broad areas:

- *Smart vehicles*, in which advanced technology units operate independently on individual vehicles.

  Smart highways, involving the installation of advanced technologies within the highway infrastructure.

The result of IVHS will be a smart traveler. Before leaving home or work, travelers will be able to determine congestion on their route (and choose another one or delay their trip), find out where the nearest transit stop is (and when the next bus/train will arrive), or be matched into a Carpool or vanpool for their trip. If they decide to drive an automobile, a route guidance system can inform them of the best path to follow to their destination.

In December, 1991, the Inter-modal Surface Transportation Efficiency Act of 1991 (ISTEA) was signed into law. ISTEA includes a number of provisions whose aim is to increase the efficiency of the existing transportation system. In clean air non-attainment areas such as Denver, highway projects that result in significant increases in capacity for single occupant vehicles are not eligible for federal funds unless the project is part of an approved congestion management system. It is thus imperative for the Denver area to improve the efficiency of the current transportation system. IVHS technology can greatly assist in these efforts and is expected to provide measurable benefits by improving safety, reducing congestion, improving mobility, enhancing economic productivity, improving energy efficiency, and enhancing environmental quality.

IVHS goals for the Denver Metro area were developed in four general categories:

- *Transportation Operations* - improve safety, reduce traffic congestion, reduce effects of incidents, support and enhance transit operations, and provide travelers with real-time information,

- *Management* - demonstrate interagency and interjurisdictional cooperation and coordination, provide information about IVHS, and create opportunities for academic participation.

- *Economics* - *use* tax dollars efficiently, take advantage of Federal funding, and promote private sector participation.

- *Environmental* - enhance regional air quality, reduce impacts of hazardous material spills, reduce the need for additional capacity, and reduce disruptions from weather-related conditions.

Potential IVHS strategies and projects were evaluated for their capabilities to meet these goals and their "fit" to Denver area conditions. Ultimately, forty-four (44) specific projects were selected as having strong possibilities of benefiting the Denver area. These were grouped under a number of global objectives as follows:

- Provide a focal point for Denver's IVHS activities.
- Improve the coverage and scope of traffic data collection.
- Develop computerized data handling and monitoring systems.
- Improve incident detection and response.
- Create a region-wide IVHS system communications network.
- Disseminate travel information region-wide.
- Improve and integrate traffic control systems region-wide.
- Reduce travel demand and enhance the attractiveness of alternative modes of travel.
- Implement a program management system.

The projects were also selected to fulfill one or mom of a set of specific IVHS functions including the following:

- Surveillance.
- Communications.
- Traveler Interface.
- Traffic Control.
- Navigation and Guidance.
- Data Processing.
- In-vehicle Systems.
- Incident Management.
- Alternative Mode Interface.
- Dispatching.
- IVHS Program Management.

The IVHS Strategic Plan which follows defines the current situation and existing conditions in the Denver area; provides background information describing IVHS systems; details regional goals and objectives; lists and describes the menu of 44 potential IVHS projects; and assigns these to the short-, medium-, and long-term time frames.

The purpose of the Strategic Plan is two-fold. First, it presents a menu of opportunities from which the future direction of IVHS activities in the Denver area can be selected. Secondly, it forms the basis for two additional documents:

- An Early Action Plan describing high-priority actions to be implemented in the Denver region in the immediate future; and

- A Master Plan which will provide priorities and costs of the Strategic Plan activities along with schedules and strategies for programming and implementation.

1.0 OVERVIEW

1.1 Introduction

The United States transportation industry is facing growing challenges of attempting to move mote people and vehicles in the face of greater social, environmental, economic and geographic constraints. It has been internationally recognized that new pavement construction is no longer in itself a complete solution to addressing transportation needs; in some cases creating unacceptable impacts in meeting existing and future travel demands. Intelligent Vehicle-Highway Systems (IVHS) have been identified as providing significant potential for alleviating current and future transportation problems.

The Clean Air Act of 1990 mandates that over the next several years, the Denver area will continue to evaluate and adopt further measures to improve air quality and regional mobility. Integrating IVHS technologies into the Denver area's transportation infrastructure may help the region avoid more serious problems in the future, especially in light of funding constraints which will limit the ability of State and local agencies to build new highways and widen existing roadways.

IVHS comprises advanced transportation technologies in two broad areas:

- ***Smart vehicles,*** in which advanced technology units operate independently on individual vehicles.

- ***Smart highways,*** involving the installation of advanced technologies within the highway infrastructure.

In combination, the two categories form the basis of the IVHS concept. IVHS also involves a significant degree of cooperation and integration of the on-vehicle units and the highway infrastructure. The result of IVHS will be a ***smart traveler.*** Before leaving home or work, travelers will be able to determine congestion on their route (and choose another one or delay their trip), find out where the nearest transit stop is (and when the next bus/train will arrive), or be matched into a carpool or Vanpool for their trip. If they decide to drive an automobile, a route guidance system can inform them of the best path to follow to their destination.

1.2 IVHS Technologies

IVHS technologies are aimed at improving transportation mobility and productivity, enhancing safety, making optimum use of existing transportation facilities and energy resources, and addressing environmental issues. A convenient way of grouping the various technologies is by function. Five broad categories of IVHS are often identified as follows:

- ***Advanced Traffic Management Systems*** (ATMS) build on established techniques such as computerized control of traffic signal systems, incident management and automated monitoring to integrate traffic control on the various facilities in an area. ATMS approaches include area-wide surveillance and

detection systems which provide information from the perspective of the overall highway network.

- ***Advanced Traveler Information Systems*** (ATIS) are used primarily to provide travelers with real-time information about road and traffic conditions, weather, transit opportunities, highway incidents, lane restrictions or other information necessary to make informed decisions. ATIS can provide information to travelers at home, at work, at public activity centers and in vehicles.

- ***Advanced Public Transportation Systems*** (APTS) apply IVHS technologies to transit fleets to improve efficiency and safety of operations and can be further expanded to include in-terminal, in-vehicle, and remote information systems as well as state-of-the-art communications and dispatching systems.

- ***Fleet Management and Control Systems*** (FMCS) is a fourth range of technologies falling under the IVHS umbrella. These technologies are intended to improve the efficiency, safety, and convenience of vehicle freight and fleet operations by monitoring vehicle location, operating status, and schedule adherence. Commercial Vehicle Operations (CVO) apply these technologies to private sector truck and van fleets. Police and emergency service vehicles also comprise appropriate fleets for these treatments.

- ***Advanced Vehicle Control Systems*** (AVCS) cover a group of technologies which can assist and support drivers in performing vehicle control functions. In the long term, these systems may relieve the driver of some or all of the driving tasks. Potential benefits of AVCS include substantial safety enhancements and major increases in highway capacity.

Within these areas, technologies and systems are recognized to be at different stages of research, development, operational testing and implementation. Each of these areas is described in more detail in Chapter 4.

1.3 Purpose and Scope of the Strategic Plan

This report presents a recommended Strategic Plan for development and deployment of IVHS technologies in the Denver Metropolitan Area. This plan recommends the direction the Denver IVHS program should follow and what should be accomplished. It identifies the IVHS technologies which are the most promising and potentially the most effective for the Metro area. Preferred approaches and technological alternatives which build on existing strengths are discussed in the context of a broad range of potential tasks. The Strategic Plan will be followed by an Early Action Plan and a Master Plan which will provide a detailed guide to implementing the Strategic Plan. They will cover issues such as project scope, timing, priorities, cost, manpower requirements, and funding scenarios.

The Strategic Plan set out in this document covers the following:

- Short term activities for the period from the present to 1995. These technologies are available and sufficiently mature that they can offer significant benefits through rapid deployment in the Denver area. IVHS activities which build on existing systems, planned projects and those addressing stated needs are the prime candidates for recommended implementation. These activities can parallel and assist in the development of a regional congestion management system and related traffic monitoring efforts. The Colorado Incident Management Coalition has completed a final report which makes 26 recommendations for projects and operational strategies which can be implemented in conjunction with the IVHS program.

- Mid term plans up to the year 2000. These technologies may not be sufficiently mature to undergo operational testing or deployment in the short term, but will likely reach this stage beyond 1995. These could include technologies and systems which are currently being developed elsewhere which might offer significant benefits to the Denver area. Mid term activities also encompass the continuation of activities from the short term.

- Possible long term ventures into the next century.

Current programs in the Denver area and the unique local socioeconomic, physical and transportation environment have been critical inputs in the development of this document. The Strategic Plan provides the basis for an Early Action Plan representing high priority actions to be implemented within the Denver region in the immediate future.

The Strategic Plan also provides a platform for the production of the Denver Area IVHS Master Plan. The Master Plan will detail the schedule and programming tasks required to implement medium and long term IVHS activities within the Denver Metro Area during the next ten to fifteen years.

The Strategic Plan is, however, broader than a list of IVHS testing and implementation projects. It is recognized that there are many other activities which must be clearly identified and programmed into the overall plan. These activities include program management and coordination tasks, mechanisms for addressing policy and legal issues, development of consistent guidelines for evaluating projects, standard setting activities, and maintenance and operational needs beyond deployment. The Plan, therefore, addresses how these areas might be accomplished.

The report is divided into six chapters. Following this introduction, Chapter 2 describes IVHS needs and benefits; Chapter 3 discusses Denver Area regional problems, goals and current programs; and Chapter 4 presents background information about IVHS. Chapter 5 presents nine global objectives of IVHS and 44 specific projects which would help attain these goals. Chapter 6 is a summary of the projects discussed in Chapter 5.

Finally, it should be noted that although the activities outlined in this document are felt to be appropriate for the Denver area, comparisons of costs, benefits, and specific project locations have not been undertaken at this stage. All projects involving IVHS technology implementation will therefore be preceded by detailed cost/benefit analyses in the Master Plan to ensure efficient use of program funds.

2.0 IVHS NEEDS AND BENEFITS

The situation that surface transportation in the Denver area and the nation is currently facing is summarized in the Strategic Plan for Intelligent Vehicle-Hinhwav Svstems in the United States (Reference 1) as follows:

> "Surface transportation in the United States is at a crossroads. The mobility we prize so highly is threatened. Many of the nation's toads are badly clogged. Congestion continues to increase, and the conventional approach of the past -- building more roads-- will not work in many areas of the country, for both financial and environmental reasons.
>
> Safety continues to be a prime concern. In 1991, 41,000 people died in traffic accidents, and more than 5 million were injured. Public transportation systems, chronically short of funds, are seen by many as an unattractive alternative to driving."

In addition, it is estimated that the social and economic costs of traffic congestion amount to $100 billion annually. Americans are estimated to spend over two billion hours annually delayed in traffic, and congestion in expected to increase by 300-400 percent over the next 15 years (Reference 2). In addition to the loss of life, traffic accidents - many caused by this same congestion - cost up to $70 billion per year.

On December 18, 1991, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was signed into law. The purpose of ISTEA is " .to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy efficient manner." ISTEA includes a number of provisions whose aim is to increase the efficiency of the existing transportation system: i.e. congestion mitigation and air quality programs ($6 billion over six years), Intelligent Vehicle-Highway Systems ($660 million), and safety programs ($4.2 million). In clean air non-attainment areas such as the Denver area, highway projects that result in significant increases in capacity for single occupant vehicles are not eligible for federal funds unless the project is pan of an approved congestion management system.

It is thus imperative for the Denver area to improve the efficiency of the current transportation system. IVHS technology can greatly assist in these efforts and is expected to provide the following benefits (Reference 1).

Safety

IVHS brings information and control to the operation of motor vehicles and therefore offers the potential for substantial improvements in traffic safety. Infrastructure improvements such as new traffic control systems will reduce the number ofvenicle stops, minimize variations in vehicle speeds, and enhance traffic flow. Safety can also be improved by more timely response to accidents and reduced exposure of stranded motorists to moving traffic.

IVHS technologies also offer unprecedented opportunities for achieving breakthroughs in crash avoidance features. Such primary safety systems could warn drivers that they are too close to a car ahead or in an adjoining lane or that they are in danger of running off the edge of the road. It has been estimated that IVHS can reduce traffic fatalities by eight percent by 2011, totalling 3,300 lives saved and 400,000 injuries avoided each year at current traffic levels. These figures, however, could prove to be quite conservative. If there am breakthroughs in IVHS applications such as collision avoidance, it is possible that these would be a dramatic reduction in the number of crashes, deaths, and injuries.

Reduced Congestion and Improved Mobility

IVHS can help reduce street and highway congestion in a number of ways. Information provided to travelers will permit many to avoid congestion by allowing them to go around the congestion, choose alternative modes of transit, or delay their trips. Rapid detection and clearing of accidents and incidents will reduce congestion and the potential for secondary collisions that frequently result and cause additional delays. Enhanced public transportation systems can divert highway traffic. Real-time, dynamic traffic control systems will adapt to traffic conditions automatically.

There will be new flexibility in organizing car- and van-pools. This will increase the number of vehicles with multiple riders, thus reducing the total number of vehicles in the traffic stream. IVHS can also guide drivers directly to available parking spaces in the downtown area and during sporting events. According to estimates, traffic congestion can be reduced as much as 20 percent by 2011 in cities that adopt IVHS technologies.

Enhanced Economic Productivity

The importance of efficient transportation to the nation's economic health cannot be overstated; nearly all economic activity uses transportation directly or indirectly. Improving the efficiency of our transportation system will boost economic productivity. Operations of many commercial and public-sector fleets will realize a variety of economic benefits from IVHS, including safety improvements, minimized delays due to traffic congestion, efficient routing of vehicles, and quicker movement of freight.

Energy Efficiency and Environmental Quality

Minimizing congestion and diverting passengers from single-occupancy vehicles will increase the energy efficiency of the transportation system. Emissions will be reduced by smoother, more evenly distributed traffic flow, as well as by increases in the use of public transit and car- and van-pooling. There is, however, some concern that any congestion relief may merely encourage more travel, thus negating most if not all gains in reduced energy consumption and pollution. This question will be researched at the national level.

Improved Public Image

Successful deployment of IVHS technologies has the potential to improve public opinion about the involved agencies because of their efforts to provide the safest and most efficient transportation system possible. Reduced driver stress, anxiety levels, and fatigue should contribute toward this end.

3.0 TRANSPORTATION IN THE DENVER METROPOLITAN AREA

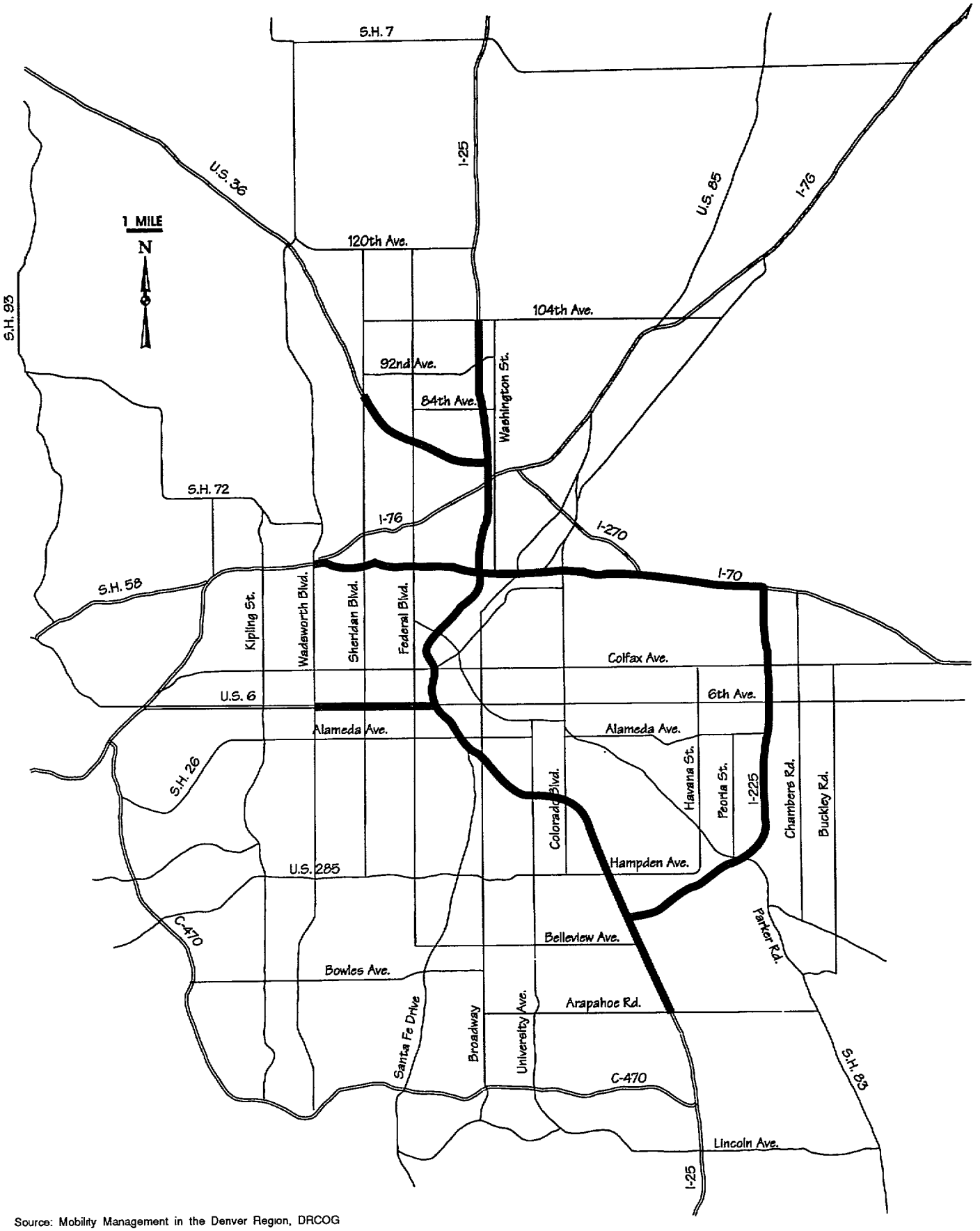
3.1 Regional Problems

The Denver region faces transportation related problems including congestion, accidents, poor air quality and limited infrastructure. In addition, Denver's regional transportation demand continues to grow while available transportation funds cannot fully address today's needs let alone future increases. Specific concerns include:

- ***Freeway and Arterial Congestion*** - Growing travel demands are resulting in increasing levels of congestion on the region's freeways and arterials. The Denver Regional Council of Governments (DRCOG) has studied congestion in the Denver Area as a part of a Transportation Systems Management (TSM) Study (Reference 3). In February 1992, DRCOG released a report which identified the region's transportation-related problems. Figure 1 (taken from this report) shows segments of Denver's freeway system which are congested during peak hours, and Figure 2 shows similar information for the arterial system. Person trips are projected to increase from current levels of 6.4 million per day to 10.7 million per day by 2010. As a result, vehicle-miles traveled (VMT) are expected to almost double over the next 20 years, from 34 million to 65 million VMT. Forces behind these problems are increasing population and employment, a tendency toward individualized transportation, and increases in frequency and length of trips. DRCOG's report notes that, "System capacity is limited due to financial, social and environmental constraints which preclude the possibility of providing sufficient roadway capacity to respond to current and expected future demands."

- ***Incidents and Incident Response*** - The Federal Highway Administration estimates that incidents account for 60 percent of the vehicle-hours lost to congestion and that 55 percent of peak urban freeway travel nationwide occurs under congested conditions (Reference 4). Incidents such as accidents, stalls, spilled loads, construction activities, and special events contribute to congestion and declining levels of service by reducing roadway capacity, resulting in backups and delays. Incidents may also lead to stop and go operation, which can cause greater congestion and secondary accidents (Reference 4). As freeway congestion increases, drivers continue to leave freeway lanes to find less congested arterial routes, ultimately increasing arterial congestion. Under worst case conditions, this congestion spills over to residential streets as motorists leave arterials for less congested collectors or neighborhood toads.

  In recognition of the severity of this problem, the Colorado Department of Transportation (CDOT), in cooperation with the National Incident Management Coalition, sponsored an Incident Management Conference in September, 1991. The direct result of this conference was the formation of the Colorado Incident Management Coalition (CIMC) to pursue coordinated incident management measures.

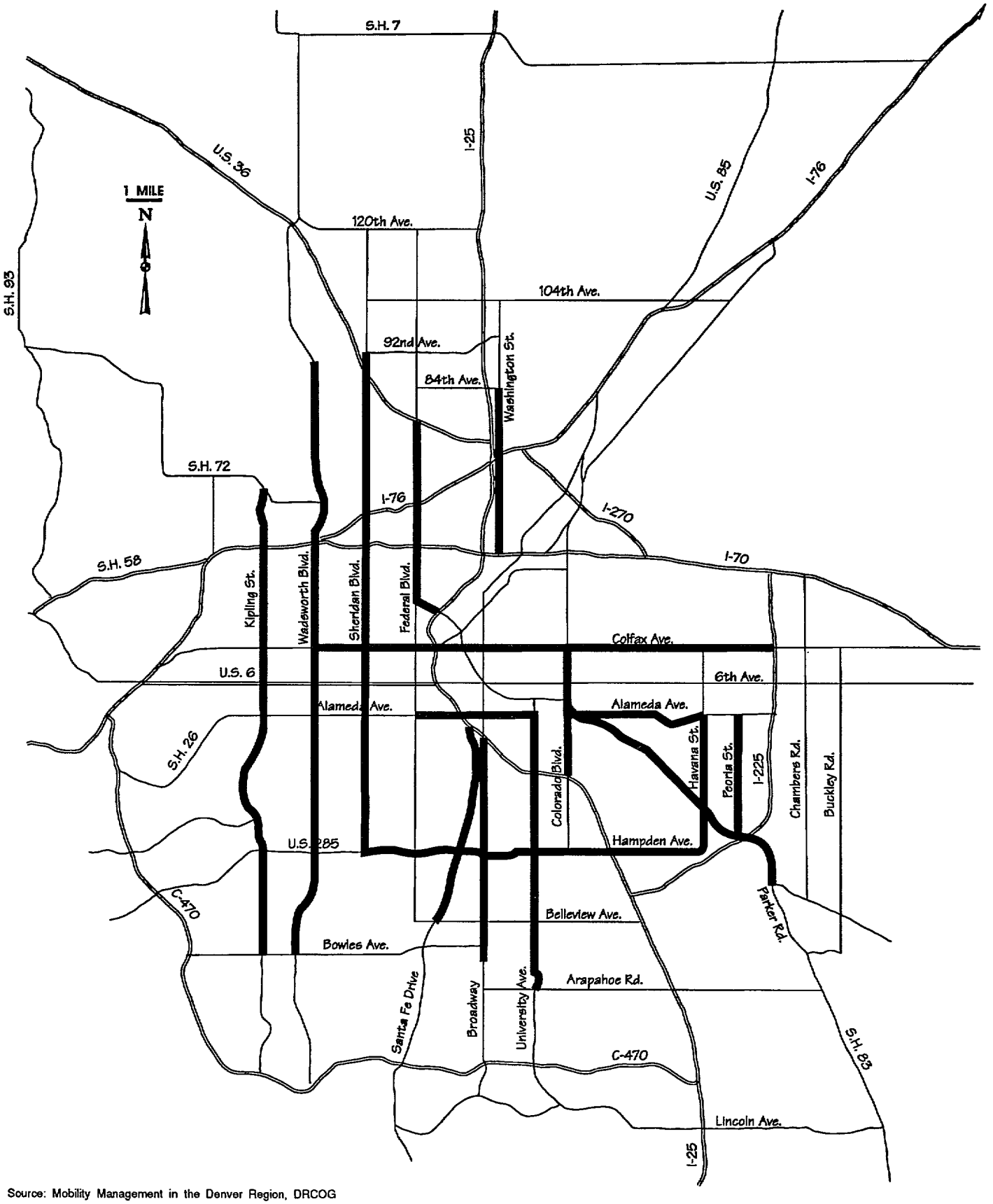


Source: Mobility Management in the Denver Region, DRCOG

STRATEGIC PLAN - IVHS STUDY FOR THE DENVER METRO AREA

Congested FREEWAY Corridors 1990

Figure 1



Source: Mobility Management in the Denver Region, DRCOG

STRATEGIC PLAN - IVHS STUDY FOR THE DENVER METRO AREA

Congested ARTERIAL Corridors 1990

Figure 2

The CIMC is a "multi-agency, multi-disciplinary group representing a variety of agencies and corporations that, in one way or another, have a specific task to carry out in responding to incidents on the roadway system or who support incident management as a tool to reduce traffic congestion (Reference 4)." Police, fire, emergency medical, local, state, and federal transportation engineers and planners and private sector organizations are all represented in the CIMC. The group has recently released a final report outlining 26 recommendations for actions to be taken to improve incident management on the regional freeway system. Marty of these recommendations are parallel or are complimentary to potential IVHS activities.

- ***Air Quality*** - Surface transportation is a major contributor to air pollution problems in the region, accounting for between 75 and 95 percent of regional carbon monoxide (CO) emissions, 30 to 40 percent of nitrogen oxides (NOx), 50 percent of the ozone producing hydrocarbons and as much as one-third to one-half of the small particulates (PM-IO) in the Denver area (Reference 3). Poor air quality is a consequence of system wide delays associated with capacity restrictions as well as VMT. The projected increase in regional VMT leads to an expectation of continued or increased air quality problems over the next twenty years. A continuance or increase in freeway and arterial congestion will compound air quality problems. Quicker and more efficient incident response, ramp metering with HOV bypasses, and improved traffic signal coordination reduce congestion on freeways and arterials respectively and ate ways to improve air quality.

- ***Transit and High Occupancy Vehicle (HOV) Utilization*** - 1990 census data for the Denver region indicate that 74.3 percent of commute trips were made in single occupant vehicles, compared to 64.2 percent in 1980. The percentage of people who Carpool to work has declined from 20.2 percent in 1980 to 12.8 percent in 1990. In addition, the percent of workers who ride the bus has decreased from 4.2 percent to 2.9 percent.

Denver regional transportation demand is growing faster than available transportation funding. Environmental and social impacts of constructing new roads limit the extent to which capacity additions can be provided. The region has therefore placed emphasis on effectively maximizing the people-carrying capacity of the existing system and adapting existing facilities and services to meet changing needs. DRCOG has identified four TSM goals for the region (Reference 3):

- Reduce vehicle demand on the transportation system.
- Improve system operations to achieve the greatest system efficiency and safety possible with minimum investment in capital facilities.
- Maintain the system to reduce the need for costly new reconstruction.
- Reduce transportation-related adverse environmental and social impacts.

Implementation of IVHS technologies can enable the Denver area to begin addressing these goals.

3.2 Regional IVHS Goals

The purpose of IVHS implementation in the Denver area is to help maximize the efficiency and safety of the existing and planned transportation system within the context of the overall regional goals. IVHS goals have been developed relating to four general categories: transportation operations, management, economics, and environmental issues. Denver area goals of IVHS implementation include the following:

Transportation Operations Goals

- Increase transportation safety. (National estimates place the benefits of deploying IVHS technology at 8% reduction in traffic fatalities within the next 20 years)(Reference 1).
- Reduce traffic congestion on regional freeways and arterials and improve regional mobility. DRCOG and other agencies in the Denver area will soon begin development of a regional congestion management plan. IVHS activities in the region should parallel and interface with the recommendations of this effort.
- Minimize the effects of non-recurring incidents on travel safety and efficiency.
- Use IVHS to support and enhance transit operations as well as other alternative modes and trip reduction measures.
- Integrate existing ramp metering, transit operations, HOV facilities, incident management programs, intercity signal coordination programs, arterial coordination programs, and other existing traffic management measures with IVHS measures.
- Positively influence travellers' decision-making by providing accurate real-time travel information.

Management Goals

- Demonstrate that interagency cooperation and coordination can be effective in the Denver Area.
- Demonstrate that IVHS projects can successfully cross jurisdictional boundaries.
- Provide information to educate transportation professionals, the public and political decision makers to enhance the image of the IVHS program in Colorado.
- Help establish Colorado as a high technology leader.
- Provide opportunities for academic research and participation.

Economic Goals

- Demonstrate efficient use of tax dollars.
- Develop a fast track IVHS program to take advantage of Federal Funding available through the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

- Make maximum use of existing, proven technologies to ensure high benefit/cost ratios.
- Create an environment which facilitates private sector financial participation and commercial involvement in areas of mutual benefit to both public and private interests.
- Minimize new construction and maintenance costs through IVHS applications.

Environmental Goals

- Achieve operational improvements through technological methods to reduce the need for additional laneage.
- Contribute to regional air quality enhancement goals.
- Reduce environmental impacts from roadway hazardous material spills through IVHS activities such as a coordinated incident management program.
- Reduce the Denver highway system's vulnerability to disruption by weather-related environmental conditions.

3.3 Current Regional Programs

The Colorado Department of Transportation (CDOT) and other agencies in the region are aware of the regional transportation problems and have implemented a number of demand management programs and advanced traffic management techniques to address them. These activities will be interfaced with and incorporated into the IVHS Strategic Plan. These efforts include the following initiatives:

- CDOT monitors and operates a network of freeway ramp meters at 28 locations, primarily in the east and south portions of the Metro Area along I-25 and I-225. These control entry to the freeway system. Real-time traffic count information from the ramp meters is currently available and is shared with the private sector in a tabular format. CDOT is in the process of upgrading the ramp metering system computer to obtain greater control and monitoring flexibility. Improved software will allow graphical displays of freeway speeds.

- The Denver Area freeways include a network of CDOT ice-detection sensors. Information received from the sensors is used to assist in scheduling and dispatching of highway maintenance vehicles during the winter. CDOT is also participating in a Federally-funded research project involving the deveiopment of new environmental sensor systems.

- CDOT currently maintains three telephone hotlines which the public can access to obtain information about weather-related or construction related roadway conditions. One is for statewide roadway conditions, another is for roads within two hours of Denver, and the third is for construction activities in the I-25 corridor. Hotline messages are kept as up-to-date as possible, however at any given time the information described could be several hours old.

- CDOT also maintains low power Highway Advisory Radio (HAR) installations located on interstate freeways on the fringes of the Metro Area. They provide motorists with information about construction activities and road closures. Although this information is updated a few times per day, again, at any given time the information may be several hours old.

- CDOT is participating with the Regional Transportation District (RTD) in the construction of a two-lane reversible Bus/High Occupancy Vehicle (HOV) facility in the North I-25 Corridor between 70th Avenue and 20th Street. When completed in 1994, the bus/HOV facility will include a state-of-the-art traffic management system with an extensive network of loop detectors, closed circuit television (CCTV) monitoring, variable message signs (VMS), and computer-aided command and control capabilities. CDOT will be responsible for the control and operations of this system. RTD will have the system monitoring functions tied into their dispatch center, although this information will be available to CDOT as well. Use of the VMS will be limited to the bus/HOV lanes, but the loop and CCTV systems have the capability to monitor mainline traffic. Construction of the bus/HOV lanes will encourage the use of transit and ridesharing programs and relieve congestion on North I-25.

- CDOT initiated the formation of the Colorado Incident Management Coalition (CIMC) in 1991. Among the topics being investigated by Coalition subgroups are the use of cellular telephones to report incidents, 800 MHz communications between agencies, the initiation of a program of courtesy patrols along I-25 and a small portion of I-70, legal and interjurisdictional issues, incident command/control and facilitation of emergency services. A broad range of agencies and private interests have participated in this effort, and the CIMC has already made important progress toward increased cooperation and dialogue between multiple agencies and jurisdictions. The CIMC has issued a final report outlining 26 potential activities, Recommendations of the Colorado Incident Management Coalition, September 1992. Many of these proposals coincide with potential IVHS activities and have been utilized in preparing this Strategic Plan. For example, several of the CIMC recommendations depend upon the implementation of a Traffic Operations Center, one of the proposed IVHS activities detailed in Chapter 5. The CIMC hosted a follow-up conference in September, 1992 to summarize the group's activities in the first year of operation, and will continue its coordination efforts into the future. Leadership of the program will be transferred to DRCOG.

- RTD is currently working to implement a Global Positioning System (GPS) for a satellite-based automatic vehicle location and computer aided dispatch system for its bus fleet. The existing communications system will be greatly enhanced through implementation of the GPS. RTD will use the system to monitor the existing bus fleet and trains when the Denver Area light rail system (MAC) becomes operational. RTD is hopeful of ultimately providing real-time transit scheduling information to its Park-n-Ride facilities and other locations.

- Ride Arrangers, the commuter assistance program operated by DRCOG, offers a number of alternative transportation services in the Metro area. Initiatives include employer incentive arrangements to promote transit, assistance in the formation of carpools and vanpools, and a guaranteed ride home program.

- DRCOG coordinates a regional traffic signal timing program to improve traffic signal timings across jurisdictional boundaries.

- CDOT participates in the multi-state ENTERPRISE program for IVHS research, development, and implementation. The ENTERPRISE program could result in technology advancements with opportunities for practical use in the Denver Area.

- Through its involvement in ENTERPRISE, Colorado has developed the C-Star program for statewide research, development, and deployment of IVHS technologies. This envisions a series of IVHS operational centers or IVHS hubs, distributed throughout the state. These will serve as focal points for required traffic and fleet management and traveler information services. The C-Star plan identified the Denver Metro Area as a key region for early IVHS demonstration and deployment.

- DRCOG has studied Denver regional mobility as it relates to the overall Regional Transportation Plan. These efforts will continue as DRCOG will soon initiate efforts to develop a Denver regional congestion management plan. Planners will complete a comprehensive evaluation of congested freeway and arterial segments and develop strategies and priorities to address congestion problems. The goal is to create an approved congestion management system for the Denver area in accordance with the requirements of ISTEA.

- The C-Star strategic plan recommends the establishment of a facility for high technology research in transportation in the State of Colorado. The Colorado Transportation Institute (CTI) has been outlined in a proposal and will likely be established within 12 months. The CTI could direct or undertake some IVHS research and development activities. The CTI would also provide access to valuable facilities such as laboratories and equipment for testing new IVHS approaches (Reference 5).

The IVHS program will seek to build on these current and proposed efforts to the maximum extent possible. This will help to maximize gains realized from each project, minimize overlap within the total initiative, and create a firm basis on which to fast-track success. These existing programs provide many opportunities for implementing IVHS technologies.

4.0 IVHS BACKGROUND

4.1 Advanced Traffic Management Systems

In the short-term, ATMS is likely to be the largest of the five main IVHS areas in the context of the Denver area's IVHS program. This arises for several primary reasons. First, many ATMS approaches build directly on existing traffic management and control systems, some of which have been implemented in Denver already, providing opportunities for ATMS-based expansions and enhancements. Second, in many ways, ATMS can be considered an umbrella over other IVHS areas. For example, many ATIS projects rely on data collection mechanisms that inherently fonn part of an ATMS.

In general, ATMS differ from traditional traffic control systems in two major respects. First, they are responsive to actual traffic flows and second, they operate in real-time. At present, control strategies tend to react to congestion on the highway after it has occurred. An ATMS will incorporate algorithms that can predict when and where congestion will occur and will act to prevent it.

ATMS will include areawide surveillance and detection systems. These provide information on the overall highway network. ATMS will also have the potential to integrate traffic control on the various facilities in an area. This requires collaborative management between the agencies responsible for managing both the freeways and the surface streets. Finally, ATMS will include rapid response incident management techniques, including incident detection, verification, and the implementation of appropriate response plans. This information will be collected at a traffic operations center, at which point truly optimal solutions to traffic problems can be developed for entire areas or regions.

A number of technologies already exist that will potentially provide the basis for future ATMS approaches. In the Denver metro area, traffic signals have been placed on entrance ramps to meter traffic onto I-2.5 and I-225. Several jurisdictions have implemented traffic signal control systems, ranging in complexity from fixed-time and isolated intersection control through the capability to provide fully-responsive control operating over an entire network. Much could be achieved through better use of these existing techniques, while there are also opportunities for the development of new signal control approaches with greater potential. In particular, adaptive traffic control technology could be integrated with real-time traffic monitoring, short-term forecasting and electronic route guidance. This would permit simultaneous optimization of signal coordination and vehicle route choice within the urban highway network. The coordination of freeways and arterials also has the potential to provide great benefits.

4.2 Advanced Traveler Information Systems

ATIS technologies aim to provide motorists with in-vehicle 'information on congestion, traffic, weather and highway conditions, and navigation, location or routing advice. ATIS will also provide pre-trip information, allowing travelers to plan their journey before

leaving the home or workplace. Many of these technologies have the potential to be among the earliest fully-operational systems implemented as part of the Denver Metro Area program.

Many technologies are available or under development in the ATIS area. One specific class of ATIS is pre-trip electronic planning systems. With these, a traveler can enter an origin and destination into a computer, and a set of muting directions is produced. These directions can be based on minimizing time, distance or cost. These systems also have strong potential for integration with transit information systems.

Traffic information broadcasting systems provide motorists with information on current highway conditions, giving an opportunity to alter a route. Some systems, like highway advisory radio, utilize. conventional AM car radios and require the driver to re-tune to a specific frequency. Others, such as the West German ARI system and the Europe-wide Radio Data System (RDS), use FM transmissions and self-tuning in-car decoders.

In-vehicle navigation and location systems provide information through in-car displays. The most sophisticated systems, termed externally-linked route guidance, provide real-time information on traffic, road and weather conditions and provide appropriate route guidance to the motorists. These displays may show the highway network and the location of the traffic problems, allowing drivers to change routes and make more informed decisions, or may provide specific routing instructions.

4.3 Advanced Public Transportation Systems

APTS can be used to provide more immediate feedback on transit vehicles to a central control point. This is achieved through the use of advanced navigation, information, and communications technologies which provide real-time data on vehicle location, information, and communications technologies which provide real-time data on vehicle location, condition, and schedule adherence. These data can permit transit fleet supervisors to initiate control strategies to optimize fleet performance, convenience, or security. A number of communication and location technologies have been developed that can support real-time operating facilities, in conjunction with on-vehicle sensors and processing equipment.

Substantial opportunities for APTS projects in the Denver area will be provided by RTD's introduction of a new GPS-based system. This will provide computer-aided dispatch of transit vehicles and automatic vehicle location (AVL). Installation of the system will begin in the fall of 1992, with operational testing and full implementation scheduled for January and March of 1993, respectively. RTD will use the system to track bus and MAC (light rail) vehicles.

APTS can also be expanded into the ATIS category when in-terminal, in-vehicle, and remote information systems for transit are included.

4.4 Fleet Management and Control Systems

The fourth of the IVHS areas addresses FMCS. This technological area incorporates a range of systems and approaches which can improve the efficiency, safety and convenience of vehicle freight and fleet operations. In this plan, the FMCS portion is considered an umbrella area which includes CVO.

CVO is used in the same manner as APTS, and for many of the same reasons. Taxicabs, package delivery services, and local and interstate trucking fleets all could be candidates for the implementation of CVO technologies, Service organizations, including medical response teams, airport landside fleets, and fire and police departments could also benefit from CVO applications. CVO is used to optimize fleet operations by identifying efficient routes and schedules; providing opportunities for real-time monitoring and control; and by satisfying the specific needs of demand responsive vehicle fleet operations.

4.5 Advanced Vehicle Control Systems

AVCS can help drivers perform certain vehicle control functions, and may eventually relieve the driver of some or all of the control tasks. The use of such technologies is likely to result in greater safety, more consistent driver behavior and improved traffic flow characteristics.

Vehicle control is complex because of the many interactions which exist between the driver and the vehicle. The driver's key roles can be defined as:

- To observe the outside environment, including highway geometry, vehicles and obstructions.
- To operate the vehicle's control system.
- To feedback observations and compensate for changing situations.
- To select an appropriate trajectory ahead.

At the most basic level, AVCS can provide the driver with useful information and warnings, based on data collected by onboard sensors. The next level is to assist the driver with the control process, by automatically adjusting the control system characteristics to the operating conditions and helping to avoid situations which give rise to loss of control. The third level is to allow the control system to intervene and manage critical situations. The highest level is for the system to completely take over the driving tasks.

Fundamental research into AVCS technologies has been taking place for several years. However, AVCS is still the least-developed of the four IVHS areas, requiring extensive additional effort before the majority of systems can be deployed for operational purposes. AVCS is therefore felt to be less appropriate for the Denver area than the other technical areas, being more suited to research and development programs than system implementation efforts. Only limited effort has therefore been directed toward AVCS in the strategic plan.

5.0 IMPLEMENTATION OPPORTUNITIES

In order to effectively monitor and manage Denver's freeway and arterial networks, better and more comprehensive information about the current status of operations on the system must be known and disseminated to travellers. This chapter covers possible strategies and projects which will help to implement the goals for transportation operations, management, economics, and environmental issues in the Denver Metro Area. These can be grouped under a number of global objectives as follows:

1. Provide a focal point for Denver's IVHS activities.
2. Improve the coverage and scope of traffic data collection.
3. Develop computerized data handling and monitoring systems.
4. Improve incident detection and response.
5. Create a region-wide IVHS system communications network.
6. Disseminate travel information region-wide.
7. Improve and integrate traffic control systems region-wide.
8. Reduce travel demand and enhance attractiveness of alternative modes of travel.
9. Implement a program management system.

These objectives were developed based upon the regional IVHS goals outlined in Chapter 3. The following matrix shows the relationships between the goals and objectives.

	OBJECTIVES								
	1	2	3	4	5	6	7	8	9
Transportation Operations Goals									
Increase Transportation Safety	●	●	●	●		●	●		
Reduce Congestion/Improve Mobility	●	●	●	●	●	●	●	●	
Minimize Effects of Incidents	●	●	●	●	●	●	●		
Support/Enhance Transit	●		●		●	●		●	●
Integrate Existing/IVHS Programs	●	●	●	●	●	●	●		●
Provide Real-Time Travel Information	●	●	●	●	●	●		●	
Management Goals									
Demonstrate Interagency Cooperation	●			●	●		●		●
Successfully Cross Jurisdictional Boundaries				●	●		●		●
Education	●		●			●			●
Establish Colorado as a Technology Leader	●	●	●			●			●
Opportunities for Academic Research	●	●	●			●	●		●

	OBJECTIVES								
	1	2	3	4	5	6	7	8	9
Economic Goals									
Efficient Use of Tax Dollars	●		●				●	●	●
Develop a Fast-Track IVHS Program	●	●			●				●
Ensure High Benefit/Cost Ratios			●				●	●	●
Facilitate Private Sector Financial Participation	●		●	●	●	●	●	●	●
Minimize New Construction/Maintenance Costs			●				●	●	●
Environmental Goals									
Operational Improvements Through Technology	●	●	●	●	●	●	●		
Contribute to Regional Air Quality Goals				●			●	●	●
Reduce Potential Hazardous Impacts	●	●		●	●	●			
Reduce Weather-Related Disruptions	●	●	●	●	●	●			

Specific projects ("potential activities"), described in the following subsections, were selected to demonstrate each of these objectives. Each objective is followed by a list of "potential benefits," representing the Chapter 3 goals which could be achieved by the implementation of some or all of the activities described.

5.1 Objective #1 - Provide a Focal Point for Denver's IVHS Activities

Potential Benefits: Reduce congestion/improve mobility; increase transportation safety; minimize effects of incidents; support/enhance transit; integrate existing/IVHS programs; provide real-time travel information; demonstrate interagency cooperation; education; encourage private sector participation; opportunities for academic research efficient use of tax dollars; develop a fast-track IVHS program; establish Colorado as a technology leader; operational improvement through technology; reduce potential hazardous impacts; reduce weather-related disruptions.

5.1.1 Potential Activity - Traffic Operations Center (TOC): The design and establishment of a Traffic Operations Center (TOC) will be central to many elements of the Denver Metro Area IVHS program. The TOC will provide a focal point for the Metro Area's IVHS-related data collection and information dissemination efforts. It will improve traffic management and incident response, helping to reduce delays, preserve air quality, and increase safety. It has also been identified as a key recommendation of the CIMC because it is vital to implementing incident management

programs and activities. Functions to be directed from or supported by the TOC will potentially include the following:

- Serve as a focal point for multi-agency and public/private sector traffic management efforts.

- Collection and processing of data from various sources including in-pavement or roadside traffic sensors, video cameras, environmental sensors and vehicles traveling on the network.

- Detection of incidents and initiation of response plans, including transmission of advisory messages to appropriate agencies.

- Provide "war room" capabilities for major emergencies which impact traffic and require coordination between multiple agencies and accurate press/media releases.

- Serve as a location for potential high technology research activities in cooperation with local colleges and universities.

- Dispatch and management of maintenance fleets and emergency service vehicles in the Denver area.

- Generation of traffic messages for ATIS broadcast technologies concerning traffic congestion, weather conditions, etc.

- Maintenance of appropriate databases for traveler enquiry services such as audiotex, videotex, and telephone hotlines.

- Network-monitoring of link travel times and communication with equipped vehicles in support of future real-time dynamic route guidance systems.

- Traffic signal control for CDOT signals along the State Highway system with a potential future interface with the signal systems of some Denver area jurisdictions.

- Command, control, and monitoring of the I-25 North bus/HOV traffic management system and the regional ramp metering system.

Conceptual planning for the TOC will include identification of the TOC's functions and responsibilities, consideration of staffing needs, selection of a site location and development of a phased implementation schedule. A key issue to be addressed in this work will be the subject of control for various functions, comparing centralized versus decentralized options for computer intelligence and operating authority. Due to the importance of the TOC within the overall context of the IVHS program, this activity is recommended for inclusion in the Early Action Plan.

Because of the time necessary to design and build a permanent TOC, an Interim TOC with reduced capabilities is also recommended. The interim facility would likely be in rented space. The interim TOC will incorporate the early action recommended activities of the CIMC, such as cellular call-in, courtesy patrol, and corridor management teams, with early action IVHS activities, as well as existing systems such as ramp metering.

CDOT and the Colorado State Patrol (CSP) have agreed in principle to share the permanent TOC facility. Advantages of a shared facility include coordinated dispatching functions--particularly during adverse winter weather, and coordinated incident response.

The proposed establishment of the TOC is consistent with the recommendations of the C-Star plan, Colorado's state-wide IVHS program. This plan discusses the establishment of a number of IVHS operations hubs in Colorado, supporting regional control of the most appropriate local IVHS approaches, and ensuring statewide system integration. The Denver area TOC would be used as a model for the IVHS hub concept, supporting the subsequent implementation of similar centers elsewhere in the state.

Time Frame: Short-term (Interim TOC Implementation, Permanent TOC Planning), Medium-term (Permanent TOC Implementation).

5.1.2 Potential Activity - Demonstration Corridor: This project will consist of planning and design to implement IVHS technologies in one or more demonstration corridors. At least one freeway or one arterial corridor should be considered for initial implementation. The project need not necessarily be constrained to a corridor application, but could also take the form of an area, consisting of a group of interchanges or an arterial grid network.

Criteria for selection of a demonstration project should include traffic volumes and levels of congestion; accident histories; costs and potential benefits; freeway versus arterial considerations; probability of operational and institutional success; ease of implementation; interface with incident management efforts; operational and maintenance requirements; communication and control requirements; and visibility to the general public.

The demonstration project will likely include several IVHS technologies. Recommendations for demonstration projects will be made in a follow-up document to the Strategic Plan.

Time Frame: Short-term, continuing into long-term.

5.1.3 Potential Activity - Traffic Operations Center Expert System
The strategic plan contains a large number of traffic control and traffic management approaches proposed for integration at the TOC location. As this process develops, it will become increasingly difficult for an operator to be fully aware of the various impacts of a control decision on the Denver area network as a whole and therefore to achieve an overall system optimization without some form of automated support.

This project will focus on the development of an expert system for the TOC's initially implemented and planned future functions. A knowledge-based system will be developed by eliciting information from system operators and other experts in the field. Among the functions that will be assessed for integration are the traffic control, demand management and ramp control strategies. The expert system will undergo operational testing prior to full deployment in the TOC. The system will initially provide advisory output and will be refined to provide fully-automated responses.

Time Frame: Medium-term.

5.2 Objective #2 - Improve the Coverage and Scope of Traffic Data Collection

Potential Benefits: Reduce congestion/improve mobility; increase transportation safety; minimize effects of incidents; integrate existing/IVHS programs; opportunities for academic research; establish Colorado as technology leader; operational improvements through technology.

5.2.1 Potential Activity - Collection of Real-time Traffic Volume and Speed Information: CDOT currently has several systems around the Metro Area to collect traffic information. The most complete system collects information at the ramps along I-25 and I-225 where freeway ramp meters are operating. In addition, CDOT has installed a number of buried inductance loops along the freeway system in conjunction with recent resurfacing projects. These do not currently have any detection equipment or communications hardware installed. In the future, traffic detectors will be installed at l/3 mile intervals along the north I-25 mainline and bus/HOV lanes in that corridor.

This activity would complete a system of vehicle detectors along all freeways where traffic monitoring is desired. The design of this system will involve several elements:

- Determine the best location for the detection equipment. This involves a trade-off between equipment cost and response time to detect incidents or changes in traffic conditions.
- Utilize existing and future ramp metering detectors for volume and speed information wherever possible.
- Determine the most appropriate detection equipment for the Denver area. In addition to the inductive loop systems already installed, infrared, microwave, optical, and image-processing based technologies have been developed.
- Determine the appropriate level of data processing between field locations (decentralized) and the TOC (centralized).

Time Frame: Short-term, continuing into medium-term.

5.2.2 Potential Activity - Advanced Arterial Surveillance: This activity will involve the use of IVHS technologies for arterial surveillance. A number of approaches with potential for arterial surveillance application are currently under investigation elsewhere in the U.S., including video image processors, radar monitoring systems and probe-based data collection techniques. By the medium-term time frame, it is anticipated that some of these technologies will be fully developed and proven. This project will therefore select the most appropriate systems for use in the Denver area.

The objectives of applying these technologies will be to enhance data collection facilities on arterial streets, providing more complete, network-wide traffic data and supporting informed traffic and incident management actions. Software enhancements will facilitate fusion of the IVHS-generated arterial data with information collected from conventional loop detectors and other sensors. This surveillance data could also provide inputs for adaptive traffic control systems such as those outlined under activity 57.4.

Time Frame: Medium-term.

5.2.3 Potential Activity - Dial-in Data Collection System This activity will seek to enhance information availability at the TOC through the establishment of a cellular telephone dial-in service. This will allow the public to relay traffic and incident information to the TOC. In the early years, detector and CCTV coverage of the freeway system could be limited, and utilizing cellular telephones will provide incident detection and verification.

The dial-in approach has demonstrated a proven track record of success in other metropolitan areas and is supported by the CIMC. This activity should therefore be coordinated with the efforts of the CIMC subgroup researching cellular call-ins. Accidents and emergencies will still be reported through the *911 system, however roadway conditions will be reported through a second number, possibly *77. The CIMC is currently evaluating the manpower requirements such a system would demand upon the CSP, Denver Police Department, and TOC staffs. In order to improve systems effectiveness, it should include a freeway signing program to encourage motorist participation and also a roadway reference system with mile markers installed at l/10 mile intervals to allow motorists to more accurately report their location. Several radio and television stations currently encourage citizen call-in, and their efforts should be closely coordinated. To prevent overloading of the existing *911 system, the dial-in system should be introduced after the implementation of the TOC (Reference 4).

Time Frame: Short-term.

5.2.4 Potential Activity-Expand Closed Circuit Television (CCTV) Coverage: Visual confirmation of incidents by CCTV is an important component of the traffic management system. Once a disruption in traffic flow is detected, visual observation is necessary to verify the location and nature of the incident. In some cases, different locations for the same incident are reported by the public. Verification confirms the actual location of an incident, and assists in the dispatching of the proper types and numbers of emergency response equipment (Reference 4). The first cameras will be

included in the HOV facility along the North I-25 corridor. Initially, additional CCTV cameras should be installed at high accident locations or capacity bottlenecks along the freeway system in the metro area. Eventually, cameras should be placed along all the freeways in the metro area and at key arterial locations near the freeways.

Several television stations have installed CCTV cameras at fixed locations to view traffic conditions along the freeway (Reference 4). Joint utilization of CCTV images, particularly for major incidents provides an additional opportunity for a public/private partnership.

Time Frame: Medium-term.

5.3 Objective #3 - Develop Computerized Data Handling and Monitoring Systems

Potential Benefits: Increase transportation safety; minimize effects of incidents; integrate existing/IVHS programs; provide real-time travel information; education; encourage private sector participation; opportunities for academic research; efficient use of tax dollars; establish Colorado as technology leader; ensure high benefit/cost ratios; minimize new construction/maintenance costs; operational improvements through technology; reduce weather-related disruptions.

5.3.1 Potential Activity - TOC Database Integration: This activity will be closely related to the development of the TOC. The success of the TOC will depend in part on large amounts of data being stored, manipulated and updated on a real-time basis. Many of the ATMS and ATIS projects included in this strategic plan will use common databases, potentially located in the TOC facility. This project will therefore focus on integration of those databases resident at the TOC. These may include the ramp metering system, freeway traffic detectors, ice monitoring systems and CCTV.

A more detailed definition of TOC database characteristics and requirements will be determined during the TOC design process. This task will identify the database requirements for current systems and those planned as part of the Metro Area's IVHS program. It will seek to develop the necessary database structure to accommodate these needs, which could be central or distributed depending on the information to be handled. This will minimize the data communications requirements, and will remove unnecessary redundancy. A suitable database system will then be developed for an operational test and evaluation prior to operation. The database will be designed to suit the needs of traffic managers, drivers, transit providers and transit users.

Time Frame: Short-term, continuing into medium-term.

5.3.2 Potential Activity - Data Fusion: This activity will follow on from the TOC database integration outlined above, beginning in the medium-term and continuing through the long-term time frame. It will involve fusion of data received at the TOC to produce a single, reliable database. The fusion process assigns reliability and longevity weightings to alternative data sources, for example inductive loops, dial-in

reports and CCTV images. This allows the most valid conclusions to be drawn when data from these sources conflict. Data fusion is therefore important in providing reliable data for both ATIS and ATMS approaches.

Software will be developed to integrate data from various sources at the TOC, including automatic input with default weightings plus operator input and override facilities. The software will then be utilized at the TOC to assist operators in resolving data conflicts and assessing traffic conditions. This will be particularly important in areas such as calculation of link travel times for ATIS devices and analysis of congestion levels in incident response planning.

Time Frame: Medium-term, continuing into long-term.

5.3.3 Potential Activity - Maintenance Fleet Management Systems: This activity will develop and implement an integrated maintenance fleet management system for CDOT Regions 1 and 6. This will aim to manage the use of these resources efficiently, particularly during extreme weather conditions when maintenance vehicles are required to keep the highway network operational. For this reason the system will include links with environmental sensor systems to allow early warning of bad weather.

The initial part of the project will assess the available weather monitoring and forecasting technologies, such as thermal mapping and ice detection systems, and select the most promising for use with fleet management systems. Additional hardware requirements beyond equipment currently installed in the Metro Area will be identified. A demonstration system, integrating the weather monitoring technologies with a computerized dispatch system, will be designed for a subsequent phase.

Dispatching of maintenance vehicles will be undertaken using specially-designed operations control software. The software will use the sensor input, weather forecasts and maintenance work schedules to allocate vehicles efficiently. The dispatch system will also be integrated with a communications system to determine vehicle location and facilitate the optimized scheduling. In this area, opportunities for increased cost-efficiency through integration with Colorado State Patrol (CSP) or RTD facilities will be considered. The potential for AVL should be investigated. Although it is not believed that an AVL system for maintenance vehicles only would be cost effective, it may be possible to reduce some of the cost by sharing an existing or proposed AVL system with another agency.

Following preliminary design, an operational test will be established using regular and emergency maintenance vehicles. Weather monitoring technologies will be installed as required to supplement the current environmental sensor network. Region 1 weather and avalanche information will be included in the database. All sensors will be linked to the operations control software at the TOC. Once the system is operational, an evaluation will be performed to assess its efficiency and utility.

Time Frame: Medium-term.

5.4 Objective #4 - Improve Incident Detection and Response

Potential Benefits: Reduce congestion/improve mobility; increase transportation safety; minimize effects of incidents; integrate existing/IVHS programs; provide real-time travel information; demonstrate interagency cooperation; encourage private sector participation; operational improvements through technology; contribute to regional air quality goals; reduce potential hazardous impacts; reduce weather-related disruptions.

5.4.1 Potential Activity-Incident Detection and Management: This project will implement incident detection and management in the Denver Metro Area. The CIMC is already actively pursuing opportunities in this area. It is therefore anticipated that this activity will be based substantially on the findings and recommendations of that group.

The implementation of the TOC facility and field data collection elements will provide a major input to incident detection and management in the Denver Metro Area. Incidents will initially be detected through the cellular dial-in service, reports from the CSP, courtesy patrols, maintenance personnel and other approaches introduced early in the program. As highway instrumentation efforts progress, automatic incident detection will be implemented using computer algorithms for data analysis. CCTV images will be used to manually verify automatic incident alarms when required. Incident detection will primarily be focused on freeways, where the impacts of incidents are most severe. However, the practicality of incident detection on arterial streets using the available data sources should also be assessed.

Operational procedures will be developed for a number of key activities. These will include generation and distribution of messages to responsible authorities. Messages will identify the nature of the incident, the response required and the authority in charge. To reduce the response time, a database of services such as tow trucks will be maintained, allowing rapid call-out when required. The TOC will also identify traffic diversion routes for major incidents and could ultimately adjust traffic signal timings to accommodate the resulting traffic. This will require agreement between the appropriate authorities concerning the circumstances under which traffic may be rerouted from freeways to arterial streets and would likely not be achievable in the short term. Incident information will also be communicated to travelers via a variety of ATIS media controlled from the TOC.

Beyond traffic incidents, a further factor to be considered in this study will be incidents relating to weather conditions. This will be addressed by collecting and analyzing data at the TOC derived from the Denver area's ice detectors and other environmental sensor systems.

Time Frame: Short-term, continuing into medium-term.

5.4.2 Potential Activity - Develop Cooperative Exchange System with Television and Radio Traffic Information Services: There are currently several radio and television stations which monitor morning and evening peak hour traffic conditions. An independent traffic information service broadcasts on a

number of other media outlets. In addition to monitoring police broadcasts, several airplanes and helicopters report on traffic conditions. Output from CDOT's ramp metering system is also monitored for current freeway speeds. This information can be valuable to the operations of the TOC, particularly to verify incidents where CCTV is not operational. Increased cooperation in data collection and reporting activities present a number of opportunities for public/private partnerships. It is likely that radio and television reporting capabilities will be included in the TOC.

Time Frame: Short-term.

5.4.3 Potential Activity - Public and Private Dispatch Systems: Another potential source of field information for incident detection and verification is utilization of the numerous public agency (for example, city and county public works departments) and private sector vehicle dispatch systems. Private participants could include delivery trucks, taxis, utility maintenance vehicles, etc. Information exchanges between their base stations and the TOC could provide very timely information.

Time Frame: Short-term.

5.4.4. Potential Activity - Pre-planned Incident Diversion Routes: This activity is a recommendation of the CIMC and the following information has been taken from their report (Reference 4). Pm-planned diversion routes will reduce the potential for delays and secondary accidents in the event of a major incident. The diversion routes can be developed by the appropriate jurisdictional agencies or by corridor management teams. The designated traffic diversion routes will identify all the resources required to implement the necessary temporary detour of traffic. Establishing traffic diversion routes for congested segments of freeways have enormous benefits for incidents which may close the freeways for hours creating gridlock and an inordinate amount of delay. In this activity, CDOT will examine methods of interfacing the pre-planned routes with IVHS elements such as radio, VMS, and various monitoring techniques.

The alternate routes should be monitored to verify that the route can handle the traffic at an acceptable level of service. The traffic signals on the diversion route may require adjustments to the timing and phasing plans based on the increased traffic demand. This may requite traffic signal equipment and communications to the local intersections to be upgraded to allow for the immediate changing of timing and phasing plans. Any type of route diversion plans developed for the freeways should have the approval of the local jurisdictions where the traffic is to be rerouted.

The implementation of the route diversion could be greatly enhanced by a Traffic Operations Center which could recommend alternate routes by controlling the messages on strategically placed variable message signs and broadcasting HAR messages.

Time Frame: Short-term.

5.4.5 Potential Activity - Emergency Service Dispatching and Routing: This activity will develop and evaluate a mechanism to improve the efficiency of dispatching and routing for emergency service vehicles. This will be based upon in-vehicle map displays, automatic vehicle location, real-time traffic data and traffic signal adjustment. Opportunities for integration of existing Opticom equipment, which is currently widely deployed throughout the region, should be considered in undertaking this project. The study should also be coordinated with incident management initiatives and the work of the CIMC.

The system will use map displays in emergency vehicles to provide optimum routes to their destinations. This will include consideration of real-time traffic information available from the TOC or distributed facilities. In conjunction with the in-vehicle routing, modifications to traffic signals will be made as required to facilitate rapid travel to the emergency scene. The AVL element will enable the operator to review progress of the emergency vehicles, making system adjustments where necessary.

The first phase of this activity will be to assess applicable technologies and produce an overall system design for emergency service dispatching and routing. Hardware and software components will be obtained and implemented for operational evaluation. This will provide a basis for system modifications and a decision on fully-operational status in the long-term.

Time Frame: Medium-term, continuing into long-term.

5.5 Objective #5 - Create a Region-Wide IVHS System Communications Network

Potential Benefits: Reduce congestion/improve mobility; minimize effects of incidents; support/enhance transit; integrate existing/IVHS programs; provide real-time travel information; demonstrate interagency cooperation; successfully cross jurisdictional boundaries; encourage private sector participation; develop a fast-track IVHS program; operational improvements through technology; reduce potential hazardous impacts; reduce weather-related disruptions.

5.5.1 Potential Activity - Create Temporary Communications to Key Locntions: In the initial stages of the IVHS program in the Denver metro area, the communications network will be limited. Communications for the current ramp metering system include dedicated cable buried along the freeway and telephone line connections from key controller cabinets to the central computer located at CDOT-Region 6. The North I-25 Corridor project includes a conduit and a fiber optic communications backbone. Before a permanent communications network can be developed, there will be a need to communicate with key locations and information collection stations. Possible technologies which would provide the necessary communications capabilities include leased telephone lines, radio (microwave, packet, spread-spectrum, etc.) and satellites.

Time Frame: Short-term.

5.5.2 Potential Activity - Develop Permanent Communications Network: This activity will include the planning, refinement, and development of a permanent communications network to tie together the IVHS elements deployed in the Denver metro area. The development of economical communications systems generally involve a trade-off between initial equipment and installation costs versus the ongoing maintenance cost and monthly user charges. Communications technologies have advanced rapidly within the past few years. State-of-the-art link-to-link communications are today achieved primarily through the use of fiber optics, which have been used in traffic control applications in the Metro Area for several years with high reliability.

The IVHS Master Plan will include a concept level communications system plan. The plan will be a guide which CDOT can use to identify conduit requirements so that the communications network can be constructed incrementally as funds become available. It will identify the following:

- Conduit locations, sizes, number, use, redundancies, etc.
- Communications nodes.

Over time, CDOT will re-evaluate the concept level plan as needed to take advantage of future funding or technology opportunities in communications.

Time Frame: Short-term, continuing into long-term.

5.5.3 Potential Activity - Communication Links to Other Centers: This activity will establish voice and/or data communication links between the Denver Area TOC and other locations in Colorado, tying together some of the statewide IVHS elements described in the C-Star plan. The purpose of these links will be information sharing on a larger-than-regional basis, particularly for weather and incidents. One benefit of these links will be to allow much more up-to-date information on weather and travel conditions along the Front Range and in the Colorado mountains to be available for the benefit of the Denver-based tourist or traveler.

Other locations for the Denver area TOC to link with could include the following:

- I-70/Eisenhower Tunnel facility.
- I-70/Hanging Lake Tunnel facility.
- CSP remote dispatching facilities.
- Ports of entry.
- Future facilities which may exist along I-70.
- Future facilities which may exist along I-25.
- Future facilities which may exist in Colorado Springs.

Time Frame: Medium-term, continuing into long-term.

5.6 Objective #6 - Disseminate Travel Information Region-Wide

Reduce congestion/improve mobility; increase transportation safety; minimize effects of incidents; support/enhance transit; integrate existing/IVHS programs; provide real-time travel information; education; encourage private sector participation; opportunities for academic research; establish Colorado as technology leader; operational improvements through technology; reduce potential hazardous impacts; reduce weather-related disruptions.

5.6.1 Potential Activity - Enhance Highway Advisory Radio: This activity will aim to enhance current methods of broadcasting traffic information on highway advisory radio (HAR). HAR service is currently being used to broadcast recorded messages concerning activities such as construction work affecting traffic. The system can also provide the potential for live audio traffic bulletins during peak periods. A continuous broadcasting option will be provided for use during major incidents. Broadcasts will be made from the TOC in light of real-time traffic or weather data. Flashing signs remotely controlled by links with the TOC will alert motorists to the need to m-tune to the HAR service during live traffic broadcasts.

CDOT is currently investigating legalities and methods of extending the existing HAR facilities, which are located on the fringes of the Denver Area, into the urbanized portions of the freeway system.

Time Frame: Short-term.

5.6.2 Potential Activity - Variable Message Signs (VMS): A system of variable message signs is included in the design for the North I-25 Corridor project. VMS offer a valuable technique to give motorists real-time information in advance of key decision points along the freeways, but can be expensive because of the structural and electronic requirements. Their use should be integrated with other information dissemination techniques. CDOT will continue to evaluate the need for additional VMS in corridor specific locations as the communications system is expanded. Other potential uses of VMS could include variable speed limit signs and lane use control signs. Variable speed limit and lane use control signs could be beneficial during inclement weather and for vehicles approaching incidents, maintenance or construction lane closures, or stop and go traffic.

CDOT Region 1 has an existing system of VMS to assist travelers moving in and out of the mountains to the west of Denver. In the short-term, Region 1 will likely shift control operations for the VMS system to the TOC.

Time Frame: Short-term, continuing into long-term.

5.6.3 Potential Activity - Radio Data System (RDS) Broadcasting: RDS is a subcarrier system developed in Europe which provides a silent data channel on existing FM radio programs. The primary purpose of RDS is to identify radio programs

and allow self-tuning receivers to automatically select the strongest signals carrying those programs. Implementation of these features in Europe has been in progress since 1984, with introduction now starting in the U.S. Initially, two RDS features will be implemented in the Denver Metro Area as follows:

- Traffic Program/Traffic Announcement (TP/TA).
- Enhanced Other Networks (EON) information.

The TP feature is used by the receiver to automatically identify radio programs which regularly provide traffic reports. The TA feature is then used by the receiver to establish when traffic information is being broadcast. These two features of RDS have already successfully been implemented in many parts of Europe. In combination, they allow the driver to select a station which regularly broadcasts traffic information, without having to listen to the non-traffic elements. If desired, the driver can instead mute the volume or listen to a cassette. When traffic information is being broadcast, the volume is increased or the cassette interrupted to allow the driver to receive the traffic message.

The EON information feature links a number of PM stations serving the same area. It can be used to monitor other stations offering the TA and TP facilities. By linking two or more of these stations with EON, the radio will be able to automatically scan these stations and re-tune to whichever one is broadcasting traffic reports,

This activity will equip participating radio stations with RDS encoding equipment. In-vehicle receivers with the TP, TA and EON functions will be obtained for operational testing and subsequent full service. A second stage will aim to implement a digital traffic information broadcasting service using RDS in the Denver Metro Area. Traffic information messages generated at the TOC will be coded into the RDS Traffic Message Channel (TMC) format using standardized lists of event messages and locations.

To facilitate the RDS-TMC service, this activity will implement a TMC message generating facility at the TOC, with a data link to the FM broadcasting station. RDS-TMC receivers will be obtained for receipt and display of the messages. It will also be necessary to undertake location coding for the Denver Metro Area prior to system implementation. CDOT is already participating in a national location coding effort through the ENTERPRISE program that would provide a platform for this effort. As with the preliminary phase of this project, the RDS-TMC facility will proceed through operational testing to full implementation in the medium-term.

CDOT will also monitor international research activities during the period to determine potential alternatives to RDS as a digital information carrier. Ongoing research efforts are evaluating digital audio broadcasting (DAB), unused television spectrum, direct satellite transmissions, cellular telephones, one-way and two-way digital paging, and AM data systems and potential communications media for RDS-TMC.

Time Frame: Medium-term.

5.6.4 Potential Activity - Teletext and Cable Television Information Systems: This activity will aim to design and implement a television-based traffic information service for the Denver Metro Area. It will use the information sources available at the TOC to compile traffic messages and generate graphical images in real time. Review of this information by travelers will be possible through a teletext service and a dedicated cable television channel. The cable channel will present a color-coded speed map of the entire freeway system. This will be in a format suitable for relay into homes in the Denver area, as well as for display on terminals in downtown office buildings. A picture insert window will also be used to show live broadcast pictures of major incidents from TOC-controlled cameras. An interface to transmit information services will additionally be developed for this system.

The teletext service will be interactive and will supplement the cable channel, offering a number of pages of traffic information, selectable by area or information type. The project will include system design and implementation for a pilot service. This will be evaluated through operational testing before a full service is offered to the public. Two private companies have already expressed interest in participation in teletext and cable television projects.

Time Frame: Short-term (cable television), medium-term (Teletext).

5.6.5 Potential Activity - Videotex Information Systems: A videotex system comprises a dedicated computer and video terminal linked to a control center via telephone lines. This can provide the user with access to a variety of data including real-time traffic, weather and transit information. These data can be obtained in the home or office, or potentially at other access points such as public buildings, parking garages or gas stations. Using telephone lines to communicate with a central database provides a two-way link for the system, thereby offering an interactive service. Kiosks to house the video terminals could be placed at numerous locations in the region, such as office buildings and activity centers.

This activity will implement an interactive videotex information service in the Denver area, based on the TOC's information database. The service will offer traffic and traveler information, including weather conditions, and route planning facilities based on teal-time information collected at the TOC. The videotex system will also provide a mechanism for transit service enquiries. The project will cover design, implementation and operational testing before a full service is offered. This activity represents a valuable opportunity for the development of a public/private partnership. One private company has expressed a willingness to work with CDOT on this project.

Time Frame: Medium-term.

5.6.6 ***Potential Activity - Audiotex Information Systems:*** The project will introduce an audiotex service for transit users in the Denver Metro Area. This will provide transit users with real-time information on bus services and schedules via a touch-tone telephone access system. The activity will build on RTD's current information services and will be enhanced by the implementation of the GPS system.

Following commissioning of the GPS service, an initial phase of this project will implement a transit enquiry facility, with manual responses supported by computer data retrieval. Through a subsequent system enhancement, it is envisioned that a single telephone number will be introduced for the audiotex service. This will allow callers to use their telephone touch-tone keys to move between menus and select the requited transit information.

Time Frame: Short-term, continuing into medium-term.

5.6.7 Potential Activity -Dynamic Route Guidance: This medium-term activity will implement a dynamic route guidance system in the Denver area. An initial task of the study will involve consideration of alternative communications media for the system, such as RDS-TMC, microwave communications, beacons or combined approaches. This should substantially build upon the major route guidance demonstrations currently underway in the U.S. Following selection of a preferred communications architecture, the project will cover the following main activities:

- Set up autonomous navigation system.
- Integrate navigation and communications system.
- Operational testing and evaluation.
- Implement full service.

Time Frame: Medium-term.

5.6.8 Potential Activity - Electronic Signage: Electronic signage involves the display of in-vehicle images replicating road signs. This has the potential to improve driver safety and convenience through increasing awareness of regulations, warning messages, etc. Electronic signage is currently being developed and demonstrated elsewhere in the IVHS arena. This activity will therefore utilize the results of these ongoing studies to implement electronic signage in the Denver area. In the medium-term, it is anticipated that a trial evaluation of in-vehicle signage could be performed using government vehicles.

Time Frame: Medium-term.

5.6.9 ***Potential Activity - Automatic Speed Control:*** An extension of the technology outlined above involves integration of the in-vehicle signage system with speed control elements. This allows vehicle speeds to be automatically adjusted according to electronically-posted limits. Again, this approach is currently being developed and demonstrated in other IVHS programs. The technology could be implemented in the Denver area in the long-term if these ongoing efforts prove successful. Again, government vehicles could be considered for initial operation of the system.

Time Frame: Long-term.

5.7 Objective #7 - Improve and Integrate Traffic Control Systems Region-wide

Potential Benefits: Reduce congestion/improve mobility; increase transportation safety; minimize effects of incidents; demonstrate interagency cooperation; successfully cross interjurisdictional boundaries; encourage private sector participation; efficient use of tax dollars; ensure high benefit/cost ratios; minimize new construction/maintenance costs; operational improvements through technology; contribute to regional air quality goals.

5.7.1 Potential Activity - Expanded Freeway Ramp Metering: The 28 freeway ramps along I-25 and I-225 currently provide the only real-time traffic count and traffic speed information along Denver's freeway system. Ramp metering has been shown to have the following benefits (Reference 6):

- Reduction of recurrent stop and go congestion on the mainline freeway improves the air quality by reducing auto emissions generated by vehicles starting from a stop condition. It also reduces fuel consumption
- Improvement of the average travel speed on the mainline improves mobility. Higher speeds generally result in reduced auto emissions (except for NOx).
- Reduction in sideswipe and rear-end type accidents improves safety.
- Increased utilization of transit and other high occupancy vehicles is possible where bypasses of the ramp meters are provided.

This future expansion of the ramp metering system should be fully coordinated with the local agency having jurisdiction over the arterial street serving the interchange. Integration of ramp metering with signal progression along the arterial can provide benefits to both the arterial and freeway systems by reducing queues which interfete with operations along the arterial. This also provides opportunities for local agencies and CDOT to coordinate efforts and cooperate in the implementation of IVHS. Bus/HOV bypass lanes should be provided wherever physically possible to allow these vehicles the priority to avoid ramp metering queues.

Time Frame: Short term, continuing into medium-term.

5.7.2 Potential Activity - Advanced Isolated Intersection Control and Simulated Signal Coordination: Advanced isolated intersection control approaches utilize vehicle detectors installed significantly in advance of intersections to control traffic signals. Early detection allows the controller to compare the option of stopping approaching vehicles on one route with holding already-stopped vehicles for a few more seconds on the other route. This analysis enables the intersection to be controlled for optimum throughput and minimum vehicle emissions. Systems that use this technique include MOVA (Modernized Optimized Vehicle Actuation) in the U.K. and OPAC (Optimized Policies for Adaptive Control) in the U.S.

Using several isolated intersection controllers, adaptive signal coordination may be simulated along an arterial section without requiring communications lii or a main computer. The concept is that, since each isolated controller would optimize signal settings for the corresponding intersection, the overall arterial would also be optimized. This study will examine the technique at a trial Denver area location. The City of Broomfield has proposed U.S. 287 as a test site for this activity.

Time Frame: Short-term, continued into medium-term.

5.7.3 Potential Activity - Reversible Lanes in Key Corridors: The initial focus of IVHS activities will be on Denver's freeway system. For the arterial systems, most of the initial activities focus on improving signal systems and coordination. One technique to improve the efficiency of the arterial system is to establish reversible lanes along major arterials which have highly directional peak hour flows. This activity would determine how monitoring and control of a reversible lane could be improved through the application of IVHS technology. The City of Denver has indicated a willingness to participate in this activity.

Time Frame: Short-term.

5.7.4 Potential Activity - Adaptive Traffic Control: Many of the jurisdictions in the region have the capability to implement some degree of traffic responsive signal control through their closed loop or centralized signal systems. These capabilities are somewhat limited in that only a few of the suburbs have systems approaching city-wide levels, various jurisdictions utilize incompatible equipment, and local staffs do not have the manpower to set the traffic responsive parameters and follow up with on-street performance evaluations.

This activity will implement real-time adaptive traffic control in a Denver area trial location. These systems monitor traffic conditions in a network and react in real-time by implementing appropriate signal settings. Principal examples of adaptive traffic control include SCOOT (Split, Cycle and Offset Optimization Technique) in the U.K. and SCATS (Sydney Coordinated Adaptive Traffic System) in Australia. Evaluations of SCOOT have indicated typical savings of 12 percent in delay over recently-optimized fixed-time systems, with benefit/cost ratios of greater than 10 in some cases.

This activity will select an adaptive traffic control system and undertake any modifications required to facilitate correct operation in the Denver area. The approach potentially could be demonstrated in the area of Mile High or Coors Stadiums, or along the MAC line in downtown Denver, requiring cooperation between CDOT and City of Denver Traffic Engineering staff. Such a location would be highly visible and should generate good publicity and response to a successful project. Adaptive traffic control could be particularly beneficial in the vicinity of a sports stadium due to its ability to constantly readjust traffic signals under unusual traffic conditions. Regional shopping centers could also be considered as highly visible demonstration areas.

Time Frame: Medium-term, continuing into long-term.

5.7.5 Potential Activity - Air-quality-responsive Traffic Control: Air quality is a major concern within the Denver area, which is periodically in violation of federal standards for carbon monoxide and ozone. The notorious "brown cloud" frequently detracts from the natural beauty of the mountain vista. This study will therefore seek to address these problems and confirm the Denver area's commitment to environmental protection. The activity will determine opportunities for the preservation of air quality through advanced traffic signal control strategies.

The purpose of the study will be to develop an air-quality-responsive signal control system based on measured traffic flows and air quality data recorded at pollution "hot spots." DRCOG is currently identifying such hot spots in the Denver area. The project could therefore build on this work, as well as DRCOG's requests for Environmental Protection Agency funding to study air quality modeling. The focus of the study will be on improving the accuracy of current computer models and combining these with air pollution meters in an adaptive traffic control system. The prototype system will then be demonstrated and evaluated in a selected location experiencing air quality problems.

Time Frame: Medium-term, continuing into long-term.

5.7.6 Potential Activity - Fourth Generation Signal Control: The first three generations of signal control can be defined as fixed-time techniques, partially adaptive approaches using fixed-time plan selection and adaptive systems such as SCOOT. Fourth generation signal control is seen as the next level of traffic signal management beyond current adaptive approaches. This advance will overcome the limitations of existing technologies, providing functions such as fast-response remedial plans, short-term traffic forecasting, increased feedback on network traffic conditions and explicit, policy-related intervention strategies for use by highway agencies. Fourth generation signal control will also integrate emerging IVHS technologies such as infrared sensors, video image processing, probe-based data collection systems and driver information systems. This will allow traffic signal timings to automatically reflect a variety of factors such as current traffic conditions, incident response plans, pollution levels and vehicle route choice.

Fourth generation signal control is a developing technology which will likely be realized through a series of incremental advancements. Short- and medium-term efforts in the Denver area should primarily focus on existing approaches proven in situations applicable to the region. Deployment of fourth generation signal control is therefore considered in the long-term time frame, building on technology developments elsewhere in combination with the earlier activities of the program.

Time Frame: Long-term.

5.8 Objective #8 - Reduce Travel Demand and Enhance Attractiveness of Alternative Modes of Travel

Potential Benefits: Reduce congestion/improve mobility; support/enhance transit; provide real-time travel information; encourage private sector participation; efficient use of tax

dollars; ensure high benefit/cost ratios; minimize new construction/maintenance costs; contribute to regional air quality goals.

5.8.1 Potential Activity - Interactive Rideshare Management and Matching System: The key objective of this activity will be to improve the convenience of ridesharing, as a mechanism to reduce single occupant vehicle use with its congestion and environmental impacts. DRCOG currently manages a rideshare matching system in the Denver area. This program is designed to assist travelers in identifying ridesharers with similar destinations and travel times. Users access the system directly from the home or workplace, obtaining information from an operator or a computer database. This enables travelers to review ridesharing options, identify travelers whose needs most closely match their own, and reserve journeys in advance. In the future, a real-time element of the system could also permit ridesharers to enter details for an immediate travel request. The database generated by such a system could potentially be integrated into the TOC when sufficiently developed and proven.

Time Frame: Short-term.

5.8.2 Potential Activity - HOV Occupancy Verification: An approach toward occupancy verification which is voluntary and places responsibility for system use with the driver must contain sufficient safeguards against abuse. The most likely form of attempted misuse will be where drivers attempt to use HOV reserved facilities when they are not carrying the required number of travelers. Frequent violation of HOV priority treatments by non-HOVs can lead to a public perception of failure of rideshare programs. The activity will therefore investigate ways in which the bypass can be prevented or the violation detected when the occupancy of the vehicle is below the required HOV level. Promising approaches will be operationally tested and evaluated prior to implementation as part of an overall HOV management strategy in later phases of the Denver area program.

Time Frame: Medium-term.

5.8.3 Potential Activity - Integrated Demand Management: This activity will integrate conventional demand management approaches with strategies facilitated by JVHS technologies. Studies are currently underway in a number of areas to examine the role of IVHS in demand management. By the medium-term time frame, therefore, it is anticipated that some approaches will be sufficiently developed and proven for use locally.

The project will determine the most appropriate demand management approaches that can be implemented in the Metro Area through the integration of IVHS technologies and traditional techniques. Systems for consideration will potentially include Automatic Vehicle Identification (AVI) for toll collection, enforcement systems for restricted areas and technologies that promote transit or HOV use. Applicable IVHS approaches will then be used in conjunction with conventional methods such as HOV lanes, as well as telecommuting. This activity should build upon the work of DRCOG in the area of demand management. The principal objective will be to enhance mobility by preventing

capacity overload through a combination of new technologies and proven management techniques.

Time Frame: Medium-term.

5.8.4 Potential Activity - Smart Cards for Transit Fare Payment: This activity will involve the design and evaluation of a smart card system for transit fate payment on RTD vehicles. Smart cards will allow regular passengers to use transit services without having to pay cash or purchase travel permits. This will enhance convenience for transit users, as well as offering increased financial control for RTD and reduced delays associated with the fare collection process. The smart card service could potentially be introduced in conjunction with RTD's construction and expansion of the MAC line.

An initial element of this project will be to identify the approach in which smart cards are to be used. This will include consideration of fare structures, prepayment versus postpayment, potential system users and other related issues. A preferred system design will be developed as a result of this work. Suitable hardware and software will then be obtained and installed in transit vehicles, and compatible smart cards will be distributed to selected transit users. The performance and utility of the system will be assessed during an operational evaluation, prior to deciding on full-scale implementation and use.

Time Frame: Medium-term.

5.8.5 Potential Activity - Transit Vehicle Status Monitoring Systems: The high capital cost of vehicle fleets makes it essential to optimize service and maintenance schedules so as to maximize utility and minimize the time vehicles are off the road. With advanced microprocessor and vehicle sensor technology, vehicle status can be monitored for operational and maintenance purposes.

This project will essentially be divided into two phases. The first phase will consider the in-vehicle equipment needed to operate real-time vehicle status monitoring. This will include sensors to measure parameters such as engine speed, brake wear, temperature of exhaust gases, oil level and fuel consumption. The sensors will link with a microprocessor so that data can be analyzed for the identification of critical conditions, and stored for long-term monitoring. In addition, this phase of the study will address the use of in-vehicle systems for monitoring passenger loading.

The second phase" of the project will be to integrate the vehicle status monitoring system with RTD's GPS-based communications system. This will enhance the system through supporting the provision of a variety of additional data. System operators will be able to review in real-time the condition of their vehicles and the number of passengers on board. These data will support informed decision-making concerning dispatching of additional or substitute vehicles. The integrated system will be operationally tested and evaluated under typical field conditions, prior to a decision on full implementation.

Time Frame: Medium-term.

5.8.6 Potential Activity - CDOT/RTD/DRCOG Partnership: Under the guidelines of ISTEA, regions such as the Denver area which are shown to be in non-compliance with air quality provisions must be willing to evaluate alternative modes of transportation. The bus and soon to be implemented light rail branches of RTD will, for all practical purposes, comprise the majority of alternative modes available in the short to medium term.

This activity would build on the initial coordination efforts begun earlier in 1992 by establishing a permanent CDOT/RTD/DRCOG liaison committee. The committee would meet a few times per year or as required to discuss topics of interest between the agencies. DRCOG would be a logical participant due to their involvement in demand management, alternative mode planning, and the development of the congestion management system for the Denver area. Matters of discussion could include:

- Advances in APTS technologies and methods of incorporating these into the Denver Regional Transportation System.
- Information sharing.
- Ridesharing and demand management activities.
- Expansion of the light rail system along the State Highway system.
- Data and communication ties between the RTD GPS system and the TOC. Once these ties are established, there is a potential (through the AVL capabilities of RTD's system) to use express buses as probes to help determine freeway speeds.
- Intermodal facilities beyond the one proposed at the I-70/Morrison interchange location. These intermodal facilities could incorporate bus, train, van, automobile, bicycle, and pedestrian traffic.

The partnership should be maintained through the long-term as it will not only provide a forum for discussion but would provide a sound basis for the establishment of more inter-agency partnerships in the future. Other agencies or jurisdictions could be involved on a periodic or permanent basis.

Time Frame: Short-term, extending into long-term.

5.9 Objective #9 - Implement a Program Management System ,

Support/enhance transit; integrate existing/IVHS programs; demonstrate interagency cooperation; successfully cross jurisdictional 'boundaries; education; encourage private sector participation; opportunities for academic research; efficient use of tax dollars; develop a fast-track program; establish Colorado as technology leader; ensure high benefit/cost ratios; minimize new construction/maintenance costs.

Activities within this objective address the broad requirements of management for the IVHS program in the Denver area. These include coordination of the main technical projects, mechanisms for addressing policy and legal issues, development of project evaluation guidelines, and standard-setting activities. By their nature, many of these program management tasks should be ongoing throughout the course of IVHS implementation. Activities described in this section are intended to be completed by the CDOT Region 6 and Headquarters staff.

For the Denver area IVHS program to be successful, CDOT department policies and organization may need to change somewhat, toward a new emphasis on technology and operations, as opposed to new construction. Support for the IVHS program at both the policy and technical levels of CDOT will be required to achieve success. Chapter 8 of the C-Star Strategic Plan details potential methods of achieving high levels of program organization, guidance, and support throughout CDOT (Reference 5).

5.9.1 Potential Activity - Program Management and Coordination:

The scope of program management and coordination is the widest of all the general projects. It will continue throughout the program, providing a systematic framework for management and coordination of operational test and deployment activities in the Denver area program. The project will incorporate the following tasks:

- Formulation and review of policy objectives.
- Definition, management and coordination of technical projects, and interface with other regional programs.
- Development and updates of program plans and identification of participants and private sector partnerships.
- Evaluation and review of technical projects.
- Assessment of socioeconomic implications.

The first of these tasks will refine the objectives presented in this Strategic Plan. It will allow program planning, management and coordination to develop in an appropriate framework. This task will review proposals for program amendments, formulate recommendations for executive action, and ensure consistency with the statewide plan.

Definition, management and coordination activities will seek to define priorities, develop proposals for project coordination, monitor the progress of individual program elements and recommend amendments for policy review. Coordination with other initiatives, such as ENTERPRISE, will be addressed here, as well as maintaining consistency and compatibility with other IVHS efforts in Colorado. Managers should strive to incorporate related local efforts, such as the recommendations of the CIMC and the upcoming congestion management system, into the IVHS program.

The third task is the development of program plans and identification of participants. This task will have three components. First, for activities in operational test and evaluation phases, project work plans and solicitation documents will be prepared. A second, closely-related activity will be to identify and solicit the support of key program

participants, public and private. Particular emphasis needs to be given to developing partnerships with the private sector. Colorado is home to a number of companies in the telecommunications, computer, electronics, and aerospace industries which should be encouraged to participate. Finally, plans for furthering the process toward implementation will be formulated, based on technology evolution, administrative frameworks, and resource constraints.

The evaluation and review task will begin with the development of guidelines for evaluating projects in the Denver area program. As projects progress, the task will assess the results of individual program elements and will develop specific evaluation mechanisms and address overall systems integration issues. An IVHS database will be developed of project results and findings.

The final element of this activity will assess the socio-economic implications of implementing IVHS technologies in the Denver area. This task will cover a range of issues including social acceptance, safety, human factors, economic implications, and legislative considerations. Antitrust laws and potential legislative changes will be examined to determine their capabilities to hinder or assist public and private sector involvement in the development and deployment of IVHS technologies.

Time Frame: Short-term, through long-term.

5.9.2 Potential Activity - Marketing and User Acceptance Surveys: This activity will support IVHS deployment in the Denver area through marketing activities and user acceptance surveys. Marketing efforts should provide a strong education component in the early stages of the program, promoting widespread understanding of IVHS approaches and benefits. These should be aimed at the general public in the region, as well as at groups with specific interests such as transit, bike or pedestrian advocates. Particular emphasis should be placed on outlining the advantages of IVHS deployment, such as reduced delays and construction expenditure, as a means to generate support and demand. Potential media for marketing efforts include promotional leaflets and brochures for distribution by program participants, as well as newspaper, radio or television articles.

Integrated with the marketing activities in this task will be user acceptance surveys. These will solicit feedback on IVHS program proposals from the Denver area public and interest groups. The objective here will be to determine the region's transportation needs as perceived by these sectors. Where technology choices are available, the user acceptance surveys will also identify preferred approaches demonstrating the necessary functionality and ease of use.

Time Frame: Short-term, through long-term.

5.9.3 Potential Activity - Participation in Standardization: An important part of the IVHS program in the Denver area will be the standardization of technologies. Throughout the emerging development of IVHS technologies and concepts, standards have been identified as the single factor that could either accelerate or impede

the commercial introduction of such approaches. This project will therefore aim to pursue standards initiatives applicable to the technologies included in the Denver area IVHS program.

As with the program management and coordination task, participation in standardization will continue throughout the program. The first stage in this process is to identify areas where IVHS standards for systems envisioned in the region are necessary. Liaison with the relevant standardization bodies should then be established. This project will pursue or, where necessary, initiate standardization activities in state, national and international forums which will be coordinated and fed into the Denver area's IVHS efforts as technologies pass from demonstration and evaluation to deployment.

Time Frame: Short-term, through Iong-term.

5.9.4 Potential Activity - Program Review and Redirection: The proposed program reviews will be undertaken every five years or mom often, as may be required to take advantage of new and promising technologies. These will aim to reexamine the program objectives in light of new developments in the IVHS field. The program review and redirection will aim to map out a long-term strategy for the program and identify more detailed projects for the subsequent five years.

This activity will comprise many tasks similar to those of the current Denver area IVHS study. It will review IVHS developments worldwide and relate them to the progress made in the Denver area. The Master Plan will be updated as required. A revised strategic plan will also be developed, providing detailed task breakdowns for projects between 1996 and **2ooo.**

Time Frame: Medium-term, through long-term.

5.9.5 Potential Activity - Public / Private Partnerships: Private sector funding has been identified by IVHS America as a potential source for up to half of the nationwide IVHS effort. Denver's IVHS program offers a number of opportunities for participation by the private sector, which traditionally has been involved with CDOT projects in several areas: in planning and design through the contracts with consulting engineers and during construction through contracts with construction companies. ISTEA encourages more innovative involvement with the private sector through long-term partnerships. The concept is to develop increased program efficiencies and leverage available public funds. Private sector involvement can result in charges for services, but this is in-line with the concept of having users (the beneficiaries) pay for services. FHWA is supportive of these efforts and is very receptive to innovative concepts.

There are a number of hurdles to be overcome in developing these partnerships. In negotiations, flexibility is essential if agreement is to be reached. Government will have to share control of the project with the private party. Selection of the private partner must be done on a competitive basis without favoritism. Because of the potential for significant private benefits, partnerships will be constantly under close scrutiny.

Because this is a new area for both the public and private sectors, it is difficult to imagine all the possible types of involvement. However, the following are some of the activities in this Strategic Plan which might include public/private partnerships:

51.1 - Traffic Ooerations Center: It is possible that the TOC could be constructed under a build/operate contract. Alternatively, the TOC could be built through a conventional construction contract approach, with a subsequent bid for operational services. The TOC operating contract should then be re-bid periodically.

A local private traffic reporting service has volunteered to help set up an interim TOC. The nature of their interest in current traffic conditions makes them, or others offering similar services, a likely participant in the permanent TOC.

5.2.1 - Collection of Real-time Traffic Volume and Speed Information: One private company has developed a subscription traffic reporting service for the freeways around London, England. The firm has installed their own network of infrared speed sensors which are placed on freeway overpasses. A license was granted by the UK Department of Transport for the installation of this equipment as well as for the sale/lease of the system's in-vehicle display devices. This type of investment in the road information infrastructure by private industry could also be applied in the Denver area.

5.4.2 - Coooerative Exchange System with Television and Radio Traffic Information Services: As mentioned above for the TOC, partnerships with media could be valuable to all participants. Currently, media efforts to report on current traffic conditions include reporters in automobiles, airplanes, and helicopters. This eyewitness information from trained observers can be important to timely incident detection and response. Speed and volume information is currently provided for broadcast. In the future, sharing of video images from mobile cameras and CCTV could be beneficial.

5.5.2 - Permanent Communications Network: There are a number of private companies which provide communications services. Joint construction and utilization of a fiber optic communications network could be an opportunity for CDOT to develop their system more quickly, at lower cost to the public and for a private company to utilize public right-of-way and unused fibers.

5.6 - Travel Information Dissemination: The Strategic Plan includes a number of concepts for disseminating traffic information throughout the Denver area. Many of these efforts will require cooperation with private communications companies to develop their full potential. For example, there is potential for the introduction of a videotex service in the Denver arca. Another application which is currently undergoing development and field trials is dynamic route guidance. There would be potential to develop a partnership in Denver similar to the Advance program in Chicago.

Time Frame: Short-term.

CDOT's philosophy should be to actively encourage participation from the private sector. This can be most logically done through the creation of a marketing plan featuring initial

contacts then following through with presentations to the local business community as pan of an educational process. Local computer, electronics, telecommunications, and aerospace companies would seem to be sensible choices for the initial contacts.

Each of the activities described within this chapter are discussed in more detail in the Early Action Plan and Master Plan documents. The Master Plan will describe the activities in a phased implementation format, describe roles and responsibilities of key participants, and identify costs and potential funding sources.

6.0 SUMMARY OF PROJECTS

6.1 System Functions

The projects described in Chapter 5 were selected to fulfill the nine global objectives and also to provide several system functions which were determined to be integral to the Denver area IVHS effort. Each Chapter 5 project is expected to address one or more of the following functional areas:

- Surveillance.
- Communications.
- Traveler interface.
- Traffic control.
- Navigation and guidance.
- Data processing.
- In-vehicle systems.
- Incident management.
- Alternative mode interface.
- Dispatching.
- IVHS program management.

Projects listed under a given objective may fulfill from one to several of the given functions. The projects were organized by what was felt to be the most appropriate objective as opposed to being placed in categories based on function. The matrix on the following page compares projects to functions. Note that each project compares with at least one function and that each function is addressed by several projects.

6.2 Timing

There is potential to implement several projects concurrently within each of the short-, medium-, and long-term timeframes. This is particularly true for a demonstration corridor project or in the implementation of a TOC.

For example, in the short-term, a freeway demonstration corridor could include surveillance such as CCTV (Activity 5.2.4), communications from an interim TOC to the field elements (5.5.1), traffic control such as ramp metering (5.7.1), traveler information such as VMS (5.6.2), incident management techniques including cellular call-in (5.2.3), preplanned diversion routes (5.4.4), enhanced HAP (5.6.1), and so on.

Similarly, implementation of a TOC (5.1.1) could also include an expert system (5.1.2), real-time surveillance (5.2. l), communications system (5.5.1 and 5.5.2), various incident management techniques (5.4. l), database integration (5.3. l), and so on.

Note that many other combinations could be applied to each example and that different sets of activities could be applied to arterial demonstration projects or other potential demonstration activities.

PROJECTS	FUNCTIONS										
	Surveillance	Communications	Traveler Interface	Traffic Control	Navigation/Guidance	Data Processing	In-Vehicle Systems	Incident Management	Alternate Mode Interface	Dispatching	Program Management
5.1 Objective #1 - Provide Focal Point											
5.1.1 TOC	●	●	●	●	●	●	●	●	●	●	
5.1.2 Demonstration Corridor	●	●	●	●	●			●	●		
5.1.3 TOC Expert System						●		●			
5.2 Objective #2 - Improve Data Collection											
5.2.1 Real-Time Volume/Speed	●			●				●			
5.2.2 Advanced Arterial Surveillance	●			●							
5.2.3 Dial-in Data Collection	●							●			
5.2.4 CCTV Coverage	●							●			
5.3 Objective #3 - Develop Computerized Systems											
5.3.1 TOC Database Integration						●		●			
5.3.2 TOC Data Fusion						●		●			
5.3.3 Maintenance Fleet Management	●									●	
5.4 Objective #4 - Improve Incident Detection/Response											
5.4.1 Incident Detection/Management	●	●		●				●			
5.4.2 Cooperative TV/Radio Exchange	●		●					●			
5.4.3 Public/Private Dispatch	●							●		●	
5.4.4 Pre-Planned Diversion Routes								●			
5.4.5 Emergency Service Dispatch					●			●		●	
5.5 Objective #5 - Region-Wide Communications Network											
5.5.1 Temporary Communications		●									
5.5.2 Permanent Communiations		●									
5.5.3 Communication Links to Other Centers		●			●			●		●	
5.6 Objective #6 - Disseminate Travel Information											
5.6.1 HAR			●		●		●	●			
5.6.2 VMS			●		●			●			
5.6.3 RDS			●		●		●	●			
5.6.4 Teletext/CATV			●		●				●		
5.6.5 Videotex			●						●		
5.6.6 Audiotex			●						●		
5.6.7 Dynamic Route Guidance			●		●		●	●			
5.6.8 Electronic Signage			●		●		●	●			
5.6.9 Automatic Speed Control			●	●	●		●	●			

PROJECTS	FUNCTIONS: Surveillance	Communications	Traveler Interface	Traffic Control	Navigation/Guidance	Data Processing	In-Vehicle Systems	Incident Management	Alternate Mode Interface	Dispatching	Program Management
5.7 Objective #7 - Traffic Control System											
5.7.1 Expanded Ramp Metering	●			●							
5.7.2 Advanced Isolated Control				●							
5.7.3 Reversable Lanes				●							
5.7.4 Adaptive Control				●				●			
5.7.5 Air-Quality-Responsive Control				●							
5.7.6 Fourth Generation Control				●							
5.8 Objective #8 - Reduce Demand/Alternate Modes											
5.8.1 Rideshare Management									●		
5.8.2 HOV Occupancy Vertification							●		●		
5.8.3 Demand Management									●		
5.8.4 Smart Cards									●		
5.8.5 Transit Vehicle Status							●		●		
5.8.6 CDOT/RTD/DRCOG Partnership			●					●	●		●
5.9 Objective #9 - Project Management System											
5.9.1 Program Management											●
5.9.2 Marketing/User Acceptance			●								●
5.9.3 Standardization		●			●	●	●				●
5.9.4 Program Review/Redirection											●
5.9.5 Public/Private Partnerships	●	●			●		●				●

The following lists separate the Chapter 5 projects into their recommended time frames.

SHORT-TERM ACTIVITIES

5.1.1 TOC (Interim Facility)
5.1.2 Demonstration Corridor
5.2.1 Real-Time Volume and Speed Information
5.2.3 Dial-in Data Collection
5.3.1 TOC Database Integration
5.4.1 Incident Detection and Management
5.4.2 Cooperative Exchange with TV/Radio
5.4.3 Public/Private Dispatch
5.4.4 Preplanned Incident Diversion Routes
5.5.1 Temporary Communications
5.5.2 Permanent Communications
5.6.1 Enhanced HAR
5.62 VMS
5.6.4 CATV Information Systems
5.6.6 Audiotex Information Systems
5.7.1 Expanded Ramp Metering
5.7.2 Advanced Isolated/Simulated Signal Control
5.7.3 Reversible Lanes
5.8.1 Rideshare Management/Matching
5.8.6 CDOT/RTD/DRCOG Partnership
5.9.1 Program Management and Coordination
5.9.2 Marketing and User Acceptance Surveys
5.9.3 Participation in Standardization
5.9.5 Public/Private Partnerships

Activities not implemented during the short-term period could also be considered in the medium-term.

MEDIUM-TERM ACTIVITIES

5.1.1 TOC
5.1.3 TOC Expert System
5.2.2 Advanced Arterial Surveillance
5.2.4 Expanded CCTV Coverage
5.3.2 Data Fusion
5.3.3 Maintenance Fleet Management
5.4.5 Emergency Service Dispatch and Routing
5.5.3 Communication Links to Other Centers

5.6.3 RDS Broadcasting
5.6.4 Teletext Information Systems
5.6.5 Videotex Information Systems
5.6.7 Dynamic Route Guidance
5.6.8 Electronic Signage
5.7.4 Adaptive Traffic Control
5.7.5 Air-Quality Responsive Traffic Control
5.8.2 HOV Occupancy Verification
5.8.3 Integrated Demand Management
5.8.4 Smart Cards for Transit
5.8.5 Transit Vehicle Status Monitoring Systems
5.9.4 Program Review and Redirection

Activities ***not implemented during*** the ***mediwn-term period could also be considered in the long-term.***

LONG-TERM ACTIVITIES
4.6.9 Automatic Speed Control
5.7.6 Fourth Generation Signal Control

Although only two activities have been identified exclusively for the long-term in this document, it is expected that CDOT will be able to augment this list during the program review process as new technologies become available. Also, short- and medium-term activities not implemented during those periods could also be considered.

6.3 IVHS Master Plan

As described in Chapter 1, this document is intended for use by CDOT as a broad guide for planning the generalities of the IVHS program for the Denver area. The Strategic Plan will be followed by a Master Plan which will outline specific projects in much greater detail. The Master Plan will include lists of participants and their interrelationships, scheduling specifics, costs, an overall program schedule, recommendations for lead agencies, and discussions of which agencies should be responsible for various activities. Each activity will be assigned priorities and risks and will be discussed in terms of potential funding sources. Interactions with other groups such as IVHS America and ENTERPRISE and interfacing with the Colorado Statewide IVHS Plan (C-Star) wiII also be addressed.

Other documents to be produced as a follow-up to the Strategic Plan include an Early Action Plan, Technical Memorandums describing a Traffic Operations Center, Denver area communications systems, and recommendations for arterial and freeway demonstration corridors, and a project Final Report.

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