ITS EARLY DEPLOYMENT STUDY
FINAL REPORT

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ITS EARLY DEPLOYMENT STUDY
FINAL REPORT

MICHIGAN DEPARTMENT OF TRANSPORTATION
MAY 1996

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STRATEGIC DEPLOYMENT PLAN

STRATEGIC DEPLOYMENT PLAN

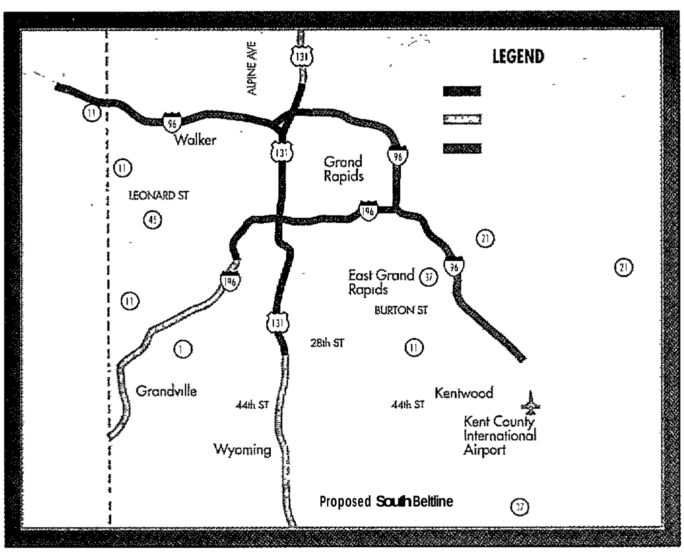
The United States has one of the most extensive and best transportation systems in the world. However, increasing vehicle miles of travel have resulted in increased congestion and decreased mobility in many urban areas. The increasing demand for transportation comes at a time when there are limited opportunities to build more roadway lanes. Land development often physically constrains the addition of lanes, limited highway funding is available, and environmental considerations often suggest that other alternatives be explored.

In response to the need to address increasing congestion and increasing demand without building additional facilities, as well as the need to better utilize the existing facilities, more and more urban areas are turning to advanced technologies. Computer, communications and process control technologies are used to improve the efficiency and safety of the transportation system. These advanced technologies are generally components of an intelligent transportation system.

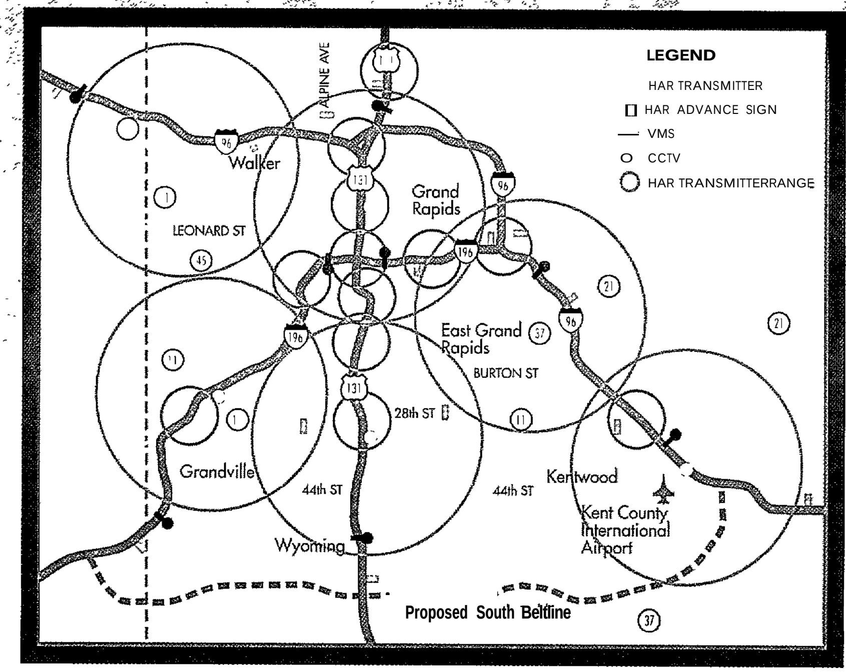
Recognizing the importance of these systems. United States Secretary of Transportation Federico Pena has identified ITS as a national priority Early deployment studies are being conducted in the 75 largest urban areas and Intelligent Transportation Infrastructure is targeted for implementation within the next 10 years in these metropolitan areas.

The purpose of the Intelligent Transportation System (ITS) Early Deployment Study for the Grand Rapids metropolitan area is to identify the ITS user services appropriate for Grand Rapids and to develop a Strategic Deployment Plan to provide these user services.

The study focused on the freeway system, and considered the arterial and transit systems to the extent that they affect the operation of the freeway system and contribute to mobility in the metropolitan area. The freeway system in Grand Rapids is basic, with I-96 to the north and east. I-196 traveling east west through downtown and US-131 traveling north-



Deployment phases for freeway management system.



Initial system recommendations

south through downtown. Though not extensive, the freeway system serves approximately 6,125,000 daily vehicle miles traveled in the area. There are areas that experience recurring congestion, such as US-131 and I-196 through downtown. Unless some action is taken, recurring congestion may be expected to increase as traffic volumes increase.

Currently, much of the congestion in the metropolitan area is related to incidents, and many issues that were identified as priorities are related to incidents These issues include both technical issues, such as rapid identification and verification of incident location, and institutional issues, such as agency coordination and recognition of the goals and objectives of all the agencies at the incident site.

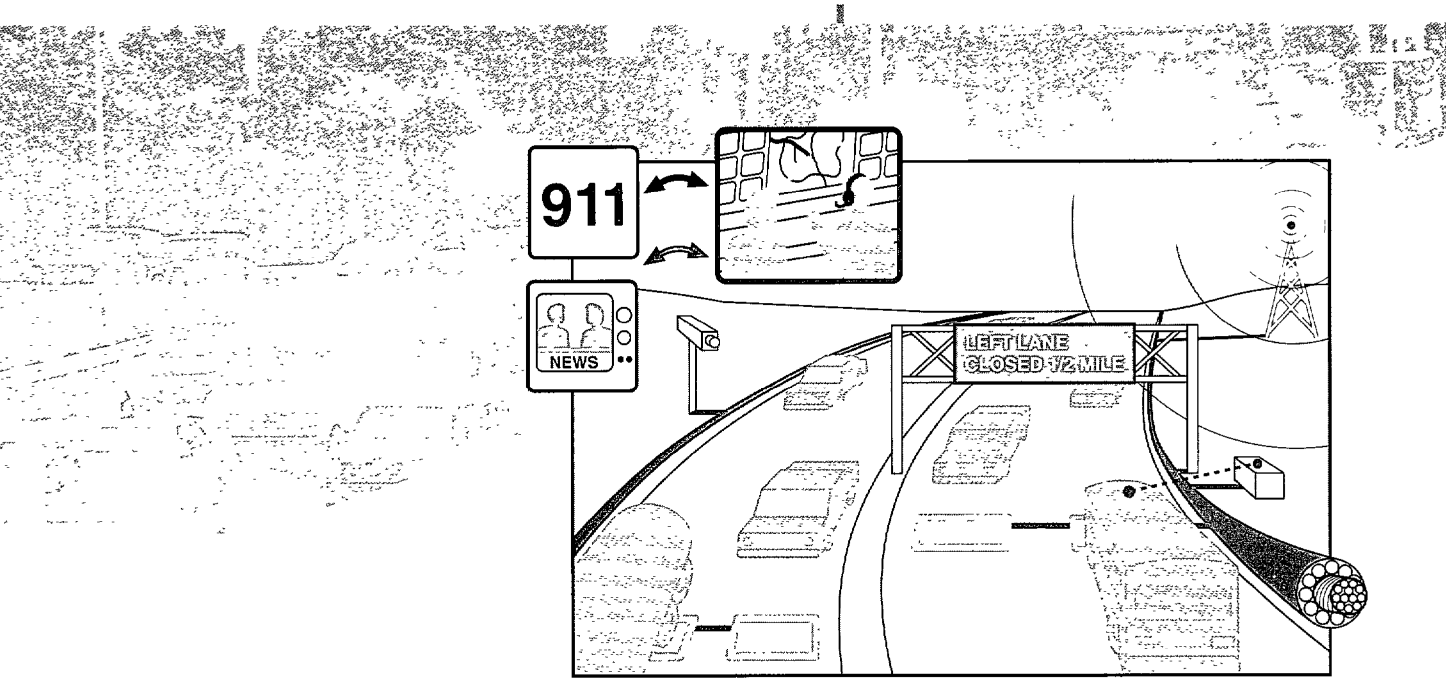
The highest priority user services, based on agency rankings, are Traffic Control, Incident Management, Hazardous Material Incident Response, and Emergency Vehicle Management. These user services address both recurring and incident related congestion, and contribute to the prompt identification and removal of incidents.

THE TECHNICAL BLUEPRINT

The system architecture may be considered a technical blueprint for the coordination of all the ITS activities. Development of the system architecture was based on an examination of three different architecture alternatives; centralized, distributed or hybrid. A distributed system is recommended to be implemented for the short-term time frame. This will provide the Grand Rapids metropolitan area with a high return

PHASE	SHORT TERM	MEDIUM TERM	LONG TERM
Annual Benefits (in millions)	$8.34	$1.07	**$0.24**
Annual Cost (in millions)			
Capital	$1.38	$0.58	**$0.74**
Operating and Maintenance	$0.65	$0.19	**$0.25**
Total	$2.03	$0.77	$0.99
Benefit Cost Ratio	$4.10	$1.39	**$0.24**
* Benefits and costs in millions of dollars			

Table EC I.Benefit Cost Ratio for Each Phase



Freeway management system includes video monitoring, vehicle detection and motorist information.

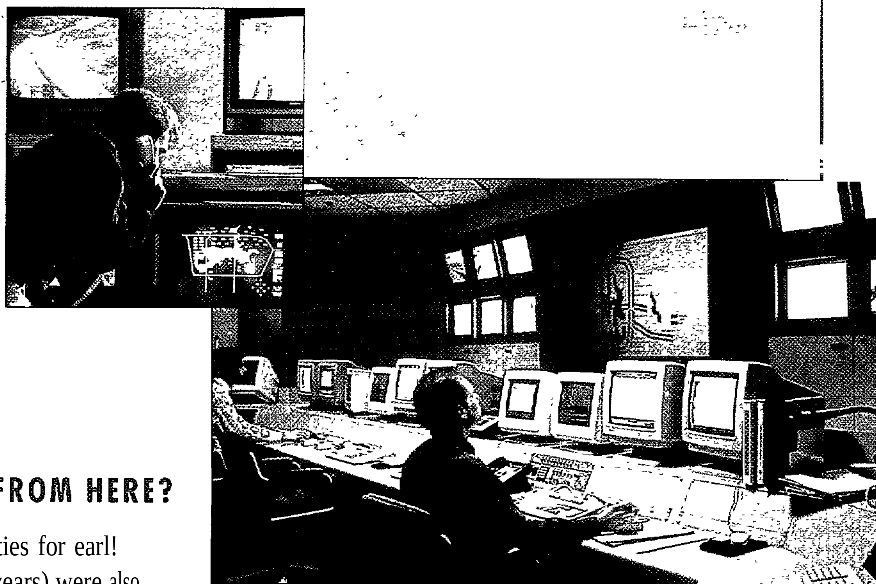
baseline system. This system will have the ability over time to evolve into a hybrid system, or eventually into a centralized system. Coordination will also be enhanced by specification of a single Traffic Operations Center (TOC). Emergencymanagementcoordination will be based on the existing 911 dispatch system, TOC operators will contact emergency responders directly using the 911 system. A separate number for non-emergency incident reports will be set up for cellular phone users. These calls will go directly to the TOC. The arterial signal control systems will remain outside of the traffic operations center in the City's traffic control room. The location of the TOC has not been finalized.

SYSTEM ELEMENTS

An examination of costs and benefits is provided for both the development of a Route 131 incident management system and the implementation of ITS technologies throughout the metropolitan area. The proposed incident management system addresses incident detection, confirmation, and response, and includes vehicle detectors, closed circuit television cameras, highway advisory radio, variable message signs and a traffic operations center, The costs and benefits associated with the development of the freeway and incident management systems were calculated for three stages of implementation. The estimated annual costs, benefits, and benefit cost ratios are shown in Table ES-l for each stage. The total capital cost for the implementation of the long term plan is estimated to be $26.2 million.

The primary focus of the implementation plan is a freeway management system. System components have been identified for a freeway management system that provides coverage of the entire metropolitan area. Based on the estimated benefit cost ratios, a freeway management system is justified for the Short (under five years) and Medium Term Plans (5 to 10 years). Deployment at the same level of concentration as the Short and Medium Term Plans is not justified under forecasted conditions for the Long Term (10 or more years); however, the plan as well as the strategic placement of the system elements at critical locations in the outlying areas should be reevaluated in the future.

Other activities identified in the implementation plan, but not reflected in the costs shown in Table ES-l, include integration of weather information into the TOC (short term), coordination with transit for the provision of information (medium term), coordination with the provision of in-vehicle information (long term), and the implementation of technologies to encourage alternatives to the single occupancy vehicle and enhance compliance with clean air mandates (long term). A number of ongoing activities have also been identified, including coordination of arterial signal systems on freeway diversion routes and coordination with emergency responders and local public works agencies. The implementation plan also includes transit applications such as automatic vehicle location systems.



Traffic Operations Center

WHERE DO WE GO FROM HERE?

Anumber of priority activities for earl! implementation (within two years) were also identified These include "early winners", projects that have a relatively low cost, require a short development time, are relatively high priority, contribute to the core infrastructure, and are expected to be successful and enhance the public image of ITS. Priority activities also include activities which set the stage for future ITS activities. Projects representing priority activities include:

- Implementation of closed circuit television cameras in selected priority locations in Grand Rapids.
- Procurement of additional portable variable message signs.
- Implementation of variable message signs at major diversion points,
- Implementation of an area-wide highway advisory radio.
- Implementation of Motorist Assist Patrol on US 131 during peak periods.
- Freeway milepost markers and overpass signing on priority facilities.
- Coordination of arterial signals for freeway diversion.
- Development of standards for construction to include ITS elements.
- Development of a policy for the provision of traveler information,
- Legislation and regulations to allow immediate removal of disabled vehicles.
- Consideration of a partnership with a private entity for the provision of traveler information in the short term.
- Coordination with planning agencies to assure inclusion of ITS projects in local and regional plans,
- Consideration of facility needs for the Traffic Operations Center during the planning and design of the Michigan State Police District 6 headquarters.

There is no specific funding set aside for ITS applications. For this reason, applications are expected to be incrementally deployed. Fortunately, significant benefits can be realized by the strategic application of selected technologies. These technologies will lay the foundation for the complete intelligent transportation system that will ultimately be implemented in Grand Rapids.

ITS Early Deployment Study
Project Advisory Committee Participants

Name	Agency
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Erin O'Brien	Michigan Department of Transportation
Joe Finch	Michigan Department of Transportation
Rise Rasch	Michigan Department of Transportation
Morrie Hoevel	Federal Highway Administration
Jere Meredith	City of Grand Rapids
David Young	City of Grand Rapids
Jeff Janke	City of Grand Rapids
Michael Jones	Ottawa County Road Commission
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Tim Rod	Michigan State Police
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Executive Summary

This Strategic Deployment Plan summarizes the results of the Intelligent Transportation System (ITS) Early Deployment Study for the Grand Rapids metropolitan area. This plan was prepared by the HNTB Corporation, TRW Inc. and Ed Swanson and Associates, Inc. study team under contract to the Michigan Department of Transportation (MDOT). A project advisory committee, which includes representatives from MDOT as well as the Federal Highway Administration (FHWA), the Grand Rapids and Environs Transportation Study (GRETS), the Michigan State Police, the City of Grand Rapids, Kent County, Ottawa County, and the Grand Rapids Area Transit Authority (GRATA), has provided suggestions and feedback throughout the study. This Strategic Deployment Plan documents the transportation system characteristics in the Grand Rapids metropolitan area, the user services that were identified as appropriate for application, a system architecture for the intelligent transportation system to be deployed, the alternative technologies available, and an implementation plan.

The study focuses on the freeway system and considers the arterial and transit systems to the extent that they affect the operation of the freeway system and contribute to overall mobility in the metropolitan area. Grand Rapids has a basic freeway system with locations that experience recurring congestion, particularly US-l 3 1 and I-l 96 through downtown. Unless some action is taken, recurring congestion may be expected to increase as traffic volumes increase.

Much of the congestion in the urban area is related to incidents, and many issues that were identified as priorities are related to incidents. These issues included both technical issues, such as rapid identification and verification of incident location, as well as institutional issues, such as agency coordination, and recognition of the goals and objectives of all the agencies at the incident site.

The highest priority user services based on agency rankings are Traffic Control, Incident Management, Hazardous Material Incident Response, Emergency Vehicle Management, Emergency Notification and Personal Security, En-Route Driver Information, and Pre-Trip Travel Information. These user services address both recurring and incident related congestion, and contribute to the prompt identification and removal of incidents.

Development of the system architecture was based on an examination of three different architecture alternatives; centralized, distributed or hybrid. A distributed type system implemented in the short term time frame offers both the highest utility and the lowest system costs of all of the analyzed alternatives. This provides the Grand Rapids metropolitan area with a high return baseline system that can evolve over time into a Hybrid type system or eventually into a Centralized type system. This evolution would take place in order to take advantage of increased economies of scale and additional opportunities for inter-agency coordination that become available as personnel and activities are consolidated.

An examination of costs and benefits is provided for both the development of a Route 131 incident management system and the implementation of ITS technologies throughout the metropolitan area. The proposed intelligent transportation system addresses incident detection, confirmation, and response, and includes vehicle detectors, closed circuit television cameras, highway advisory radio, variable message signs and a traffic operations center. The costs and benefits associated with the deployment of an intelligent transportation system were calculated for three phases of implementation. The estimated incremental annual costs, benefits, and benefit cost ratio are shown in Table ES-I for each phase. The total capital cost for the implementation of the long term plan is $26.2 million.

Table ES-l. Incremental Benefit Cost Ratio for Each Phase

Phase	Short Term	Medium Term	Long Term
Annual Benefits (in millions)	**$8.34**	**$1.07**	**$0.24**
Annual Cost (in millions)			
Capital	$1.38	$0.58	**$0.74**
Operating and Maintenance	**$0.65**	**$0.19**	**$0.25**
Total	**$2.03**	**$0.77**	**$0.99**
Benefit Cost Ratio	**4.10**	**1.39**	**0.24**

* Benefits and costs in millions of dollars

The primary focus of the implementation plan is a freeway management system. System components have been identified for a freeway management system that provides coverage of the entire metropolitan area. Based on the estimated benefit cost ratios, a freeway management system is justified for the Short Term Plan (under 5 years) and the Medium Term (5 to 10 years). Deployment at the same level of concentration as the Short Term Plan is not justified under forecasted conditions for the Long Term (10 or more years); however, the plan as well as the strategic placement of system elements at critical locations in the outlying areas should be reevaluated in the future.

Other activities identified in the implementation plan, but not reflected in the costs shown in Table ES-l, include integration of weather information into the TOC (short term), coordination with transit for the provision of information (medium term), coordination with the provision of in-vehicle information (long term), and the implementation of technologies to encourage alternatives to the single occupancy vehicle and enhance compliance with clean air mandates (long term). A number of ongoing activities have also been identified, including coordination of arterial signal systems on freeway diversion routes and coordination with emergency responders and local public works agencies. The implementation plan also includes transit applications such as automatic vehicle location systems.

A number of priority activities for early implementation (within two years) were also identified. These include “early winners”, projects that have a relatively low cost, require a short development time. are relatively high priority, contribute to the core infrastructure, and are expected to be successful and enhance the public image of ITS. Priority activities also include activities which set the stage for future ITS activities. Projects representing priority activities include:

- Implementation of closed circuit television cameras in selected priority locations in Grand Rapids.
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- Development of standards for construction to include ITS elements.
- Development of a policy for the provision of traveler information.
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- Coordination with planning agencies to assure inclusion of ITS projects in local and regional plans.
- Consideration of facility needs for the Traffic Operations Center during the planning and design of the Michigan State Police District 6 headquarters.

There is no specific funding set aside for ITS applications. For this reason, applications are expected to be incrementally deployed. Fortunately, significant benefits can be realized by the strategic application of selected technologies. These technologies will lay the foundation for the complete intelligent transportation system that will ultimately be implemented in Grand Rapids.

Chapter 1
Introduction

INTRODUCTION

This report summarizes the results of Phase II of the Intelligent Transportation System (ITS) Early Deployment Study for the Grand Rapids metropolitan area. The purpose of this study was to identify the ITS user services appropriate for Grand Rapids and to develop a Strategic Deployment Plan based on these user services. Following a discussion of the transportation characteristics in the Grand Rapids metropolitan area and an examination of the user services, this Strategic Deployment Plan documents the system architecture, alternative technologies. and implementation plan for an intelligent transportation system in the Grand Rapids metropolitan area.

PARTICIPATING AGENCIES

This Early Deployment Study is a project administered by the Michigan Department of Transportation (MDOT). A project advisory committee, which includes representatives from MDOT, the Federal Highway Administration (FHWA), the Grand Rapids and Environs Transportation Study (GRETS), the Michigan State Police, the City of Grand Rapids, Kent County, Ottawa County, and the Grand Rapids Area Transit Authority (GRATA), has provided suggestions and feedback throughout the study.

INTELLIGENT TRANSPORTATION SYSTEMS

The United States has one of the most extensive and best transportation systems in the world. However, increasing vehicle miles of travel have resulted in increased congestion and decreased mobility in many urban areas. Highway travel delays in urban areas total more than two billion hours annually, costing billions of dollars in productivity and lost working hours'. This situation, if left unchecked, is expected to get even worse. According to a study by the Federal Highway Administration, delays on urban freeways are expected to increase by 360 percent in the central cities and by 433 percent in outlying areas in the twenty years between 1985 and the 2005[2].

The increasing demand for transportation comes at a time when there are limited opportunities to build more roadway lanes. Construction and reconstruction activities are often physically constrained by urban development. The addition of roadway capacity is also limited by environmental regulations which discourage (or in some cases do not allow) the construction of additional facilities for single occupancy vehicles, and by social opposition to roadway projects which facilitate low density development and urban sprawl.

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1 US Department of Transportation, *Moving America, New Directions, New Opportunities. A Statement of National Transportation Policy, Strategies for Action.* February 1990.

2 Federal Highway Administration, "Urban and Suburban Highway Congestion." Working Paper No. 10, Washington, DC, December 1987.

In response to the need to address increasing congestion and increasing demand without building additional facilities, and in response to the need to better utilize the existing facilities, more and more urban areas are turning to advanced technologies. These advanced technologies are generally components of an intelligent transportation system (ITS).

Intelligent transportation systems were formerly called intelligent-vehicle highway systems (IVHS), however, the name was changed to reflect the fact that these systems encompass not only highways and cars, but all transportation modes including transit, rail, and air, as well as intermodal connections. Commercial vehicle operations, highway, rail, air, waterway, and intermodal connections are all incorporated into ITS. Furthermore. note the inclusion of the term system, which emphasizes that all modes and functions of the transportation system should be integrated to provide optimal efficiency and system performance.

As a general definition, intelligent transportation systems are systems that utilize advanced technologies, including computer and process control technologies, to enhance the safety and efficiency of the transportation system. Although there is no distinct origin to ITS. activities can be traced to a number of projects that began in the 1970's and 1980's;. These activities were initiated in a number of different countries, and involved government, industry, academic institutions, and trade and professional organizations. The various activities gradually merged into a single concept, evolving to focus on the transportation system, and not merely on discrete system components.

In the United States, individual cities and states undertook early activities. Federal involvement was formally initiated with the Intermodal Surface Transportation Efficiency Act (ISTEA), which was passed in December, 199 1. This legislation authorized $660 million of federal funds to support ITS activities over a six-year period. This funding, which was subsequently increased to over $900 million. has been used for early deployment planning studies such as this and other ITS projects.

FOCUS OF ITS STUDY

The major focus of the Early Deployment Study is on the freeways in the Grand Rapids metropolitan area. This focus on the freeways is justified by the fact that freeways are the backbone of the transportation system in the Grand Rapids area; Though not extensive, the freeway system serves approximately 6,125,000 daily vehicle miles traveled, a significant portion of the traffic in the Grand Rapids area. Because freeways serve so much of the travel in Grand Rapids, investments that have a positive impact on freeway operations can result in substantial benefits.

Arterials and transit. while an important element in the transportation system, play a smaller role in terms of overall mobility in the metropolitan area. The smaller role of arterials and transit is reflected by the fact that arterials and transit are included in the plan where they impact freeways (for example, arteriais may serve as alternative routes when there is an incident on the freeway), and to the extent that they impact the transportation system as a whole.

3 Discussion based on *Smart Highways, Smart Cars,* Richard Whelan, Antech House, inc., 1995.

FOCUS OF STRATEGIC DEPLOYMENT PLAN

The focus of the intelligent transportation system described in this Strategic Deployment Plan reflects the priority user services identified in Phase I of the Early Deployment Plan. The primary component of the Strategic Deployment Plan is a freeway surveillance and advanced traffic management system. This system addresses the highest priority user services: Traffic Control, Incident Management, Hazardous Material Incident Response, Emergency Vehicle Management, Emergency Notification and Personal Security, En-Route Driver Information, and Pre-Trip Travel Information. These and all of the other user services are discussed in Chapter 3.

The Strategic Deployment Plan also contains provisions for the implementation of intelligent transportation technologies related to transit. This component addresses the transit related highest priority user services: Public Travel Security and Public Transportation Management. This component also encourages alternatives to the single occupancy vehicle.

ORGANIZATION OF REPORT

Following this introductory chapter, Chapters 2 and 3 summarize the findings of Phase I of the Early Deployment Study. Chapter 2 provides a discussion of the transportation system characteristics, problems, and opportunities in the Grand Rapids area. Chapter 3 defines the user services, and identifies which ones are appropriate in the short, medium, and long term.

Chapters 4 through 7 address the results of Phase II of the study, including the system architecture, the technologies that may be used for an intelligent transportation system, the expected benefits and costs of the proposed system, and the plan for implementation.

Chapter 4, which examines the system architecture, presents the three alternative architectures considered, and discusses the analysis procedure used to select the recommended architecture.

Chapter 5 provides a discussion of the technologies that could be used for an intelligent transportation system. Following a discussion of the characteristics, benefits and limitations of various technologies recommendations regarding the kinds of technologies to be implemented in the near term.

Chapter 6 analyzes the costs and benefits that would be expected to result from implementation of the proposed intelligent transportation system. Costs are estimated for individual components. as well as for the recommended system, and benefits are estimated for the system.

Chapter 7 discusses the proposed implementation plan. Priorities, an implementation schedule, and an operations plan are presented along with a discussion on interagency coordination, funding issues and opportunities for public/private partnerships.

Chapter 2
Transportation System Characteristics

JURISDICTIONS AND AFFECTED AGENCIES

The focus of the ITS Early Deployment study is the Grand Rapids metropolitan area which encompasses portions of Kent and Ottawa Counties. The areas within these counties include a number of incorporated cities other than Grand Rapids, such as the cities of East Grand Rapids, Kentwood, Wyoming, Grandville, and Walker. The study area includes Muskegon and Allegan counties in regards to the impact of tourist traffic destined to and from these counties on the Grand Rapids metropolitan area. While coordination and cooperation between these agencies is significant at all times, it becomes critical during incident management and in other situations where a number of agencies are involved and time is imperative.

MAJOR FACILITIES IN THE GRAND RAPIDS AREA

The primary emphasis of this study is on the major trunk-line system in the Grand Rapids area. The major facilities that were considered in this study include the freeways, both interstate and non-interstate facilities, and major arterials. Transit facilities and services have been considered where they have influenced freeway and arterial operations.

Freeways

The freeway system in Grand Rapids is basic, with I-96 to the north and east, I-l 96 traveling east-west through downtown and US-131 traveling north-south through downtown. Though not extensive, the freeway system serves approximately 6,125,000 daily vehicle miles traveled in the area.

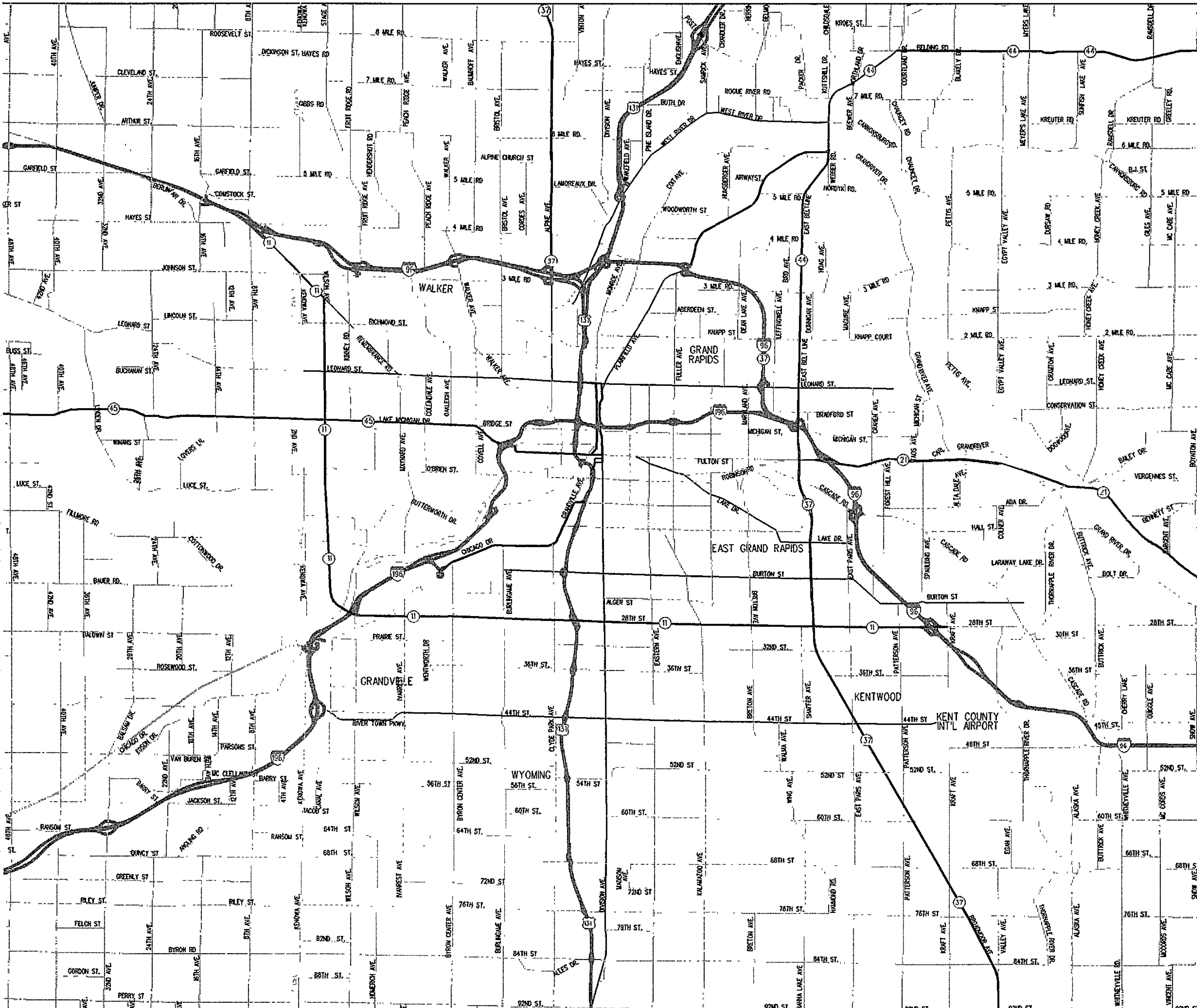
Major freeway facilities in the Grand Rapids area are shown in Figure 2-l and include:

- I-96 north and east of downtown;
- I-196 through downtown;
- US-131 through downtown;
- I-296 combines with US-131 between I-196 and I-96 to the north of downtown.

Arterials

Grand Rapids has an extensive system of principal arterials, comprising approximately 400 lane miles. Principal arterials serve major activity centers, linking these activity centers to freeway facilities. Principal arterials also serve as a primary means for mobility to trips that are not served by freeway facilities (for example, a trip directly east of downtown may be served by Route M-21, Fulton Street).

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN



LEGEND

INTERSTATES / U.S ROUTES

MAJOR ARTERIALS

MINOR ARTERIALS

FIGURE 2-1

ROADWAY SYSTEM
GRAND RAPIDS METROPOLITAN AREA

Ideally, arterials also serve as alternate routes to the freeway. Diversion of traffic from freeways to arterials when freeway facilities are under construction or when there is an incident on the freeway can result in decreased overall delay. However, not all arterials are suitable as alternate routes for freeway traffic. For example, Route M-l1 (28th Street) currently exhibits both congestion and high accident rates. which is a deterrent from suggesting it as an alternate route. An arterial used as an alternate route would preferably run approximately parallel to the freeway, would have adequate access onto and off of the freeway. and would have adequate capacity and operating speeds. Arterial capacity is influenced not only by the number of lanes in each direction but also by the signal timing along the facility. Thus, the capability to vary signal timing plans in response to a large volume of traffic diverting from the freeway significantly enhances the effectiveness of an arterial as an alternative route. This is discussed in greater detail later in this chapter under *System Characteristics.*

Major arterial facilities in the metropolitan area are also shown in Figure 2- 1 and include:

- Route M- 11 (Wilson Ave. and 28th St.) west and south of downtown;
- Route M-45 (Lake Michigan Drive and Fulton Street) west of downtown and terminating at Business Route 131;
- Business Route I- 196 (Chicago Drive) southwest of downtown;
- Route M-37 (East Belt Line and Alpine Ave.) southeast and northwest of downtown;
- Route M-2 1 (Fulton St.) to the east of downtown terminating at Route 37;
- Route M-44 (East Belt Line) northeast of downtown;
- Plainfield Avenue (Route M-44 Connector) northwest of downtown connecting Route 44 and I-**96.**
- 44"' Street south of downtown connecting I-196 and US-1 3 1 with the Kent County Airport.
- Division Avenue/Plainfield Avenue from the south of downtown to the connection at I-96.
- Leonard Street traveling east/west through downtown.
- Remembrance Road to the west of downtown connecting Route M-l 1 to Leonard Street.
- Burton Street traveling east/west through East Grand Rapids.
- Lake Drive connecting Fulton Street and Route M-37 (East Belt Line) in East Grand Rapids.
- West River Drive to the north of downtown.
- Alpine Avenue from the northern Route M-370-96 interchange to the intersection with Leonard Street.

Transit Facilities And Services

All transit service in the Grand Rapids area is managed by a single transit agency, the Grand Rapids Area Transit Authority (GRATA). GRATA provides fixed route transit service and manages paratransit service which includes three providers. GRATA has recently acquired a new server for paratransit scheduling.

While GRATA is not directly considering any ITS initiatives, they are planning a downtown transit center and have opened an interim transit center in November of 1995. The interim center is on Ionia Avenue north of Lyon Street. The future downtown transit center is anticipated to be completed within five years and will be near the new arena. The center will provide centralized services including a transit service hub running with a pulse schedule, as well as a customer service center and a sales department.

GRATA. like many transit agencies. is facing severe challenges. Fares have been increased and service reduced to a point where it is not feasible to make additional changes. GRATA is also hampered by an old fleet of vehicles. Plans are to procure 25 new buses in April of 1996 with another 30 at a later date. The new buses should be a considerable improvement over the existing fleet in terms of passenger comfort since the new buses will be air-conditioned.

The existing buses are equipped with a 440 MHz radio communication system which provides for central dispatch from the Wealthy Street garage. Given the reductions in service that have been made, the fleet is still able to accommodate the peak period demands.

Intermodal Facilities

There are a number of inter-modal facilities in the Grand Rapids area, including aviation facilities at Kent County Airport. facilities for truck/rail interface, an AMTRAK station, and passenger bus service. Most of the truck/rail facilities are in industrial areas along the US- 131 corridor, while the AMTRAK station is on the comer of Wealthy Street and Market Street.

AMTRAK currently offers service to Chicago and the Lake Michigan shoreline seven days a week. This service had been cut in 1994; however, a task force named WESTRAIN helped reinstate the current seven day service for a yearlong trial in 1995. The future of this service depends on the success of the train ridership during this trial period.

Grand Rapids is the center of many major manufacturing and service companies which maintain trucking fleets. These companies include Meijer, Spartan, AMWAY, Steel Case, UPS, Gainey, and S. Abrahams and Sons. User services oriented toward commercial vehicles will need to consider the location and activities of these facilities.

Planned Facilities

A variety of transportation projects have been proposed or are planned for implementation in the Grand Rapids area. The impact of these proposed and planned projects on the transportation system will vary, depending on the magnitude of the project. The following information on planned facilities is based on the GRETS “2015 Long Range Transportation Plan for the Grand Rapids Metropolitan Area" published in 1993.

Freeway and Arterial Facilities

The GRETS Long Range Plan includes recommendations for a number of facilities in the Grand Rapids area. There is a facility proposed that will connect I-196 to I-96 along the south side of the city and will be called Route M-6 (South Belt Line). There are also recommendations to provide capacity improvements to the existing roadway network, mostly to the existing arterials. The following is a list of the capacity improvement projects for the major arterials in the study area mentioned in the long range plan.

- M-37. increase to a four (4) lane boulevard between 29th Street and 76” Street;
- M-45, increase to four (4) lanes between 68th Avenue and 24” Avenue and increase to five (5) lanes between Wilson Avenue and just east of Kinney Road (completed);
- M-44, increase to a four (4) lane boulevard between I-96 and Plainfield Avenue.
- M- 11, increase to six (6) lanes in three segments, one (1) in Grand Rapids/Kentwood and two (3) in Wyoming.

A new bridge over the Grand River between Plainfield Avenue and West River Drive has been discussed in planning meetings. However, it is not outlined or discussed in the Long Range Plan.

The 2015 Long Range Plan addresses the growth in miles of congestion and congested vehicle miles traveled. Under the existing plus committed scenario, GRETS foresees a 48% increase in the amount of congested miles and 219% increase in the congested vehicle miles of travel for the year 20 15 in the study area.

The 2015 Long Range Plan also addresses the anticipated locations within the study area where capacity deficiencies may occur. The most noteworthy section is the Route M-l 1 corridor from just north of Richmond Street to the I-96 interchange to the southeast of downtown. This section has a forecasted v/c ratio of over 1.25.

Transit Facilities

GRATA is currently developing short and long range transit plans that will include an inventory and analysis of the existing transit operations and services in the metropolitan area, analysis of transit circulation in downtown Grand Rapids, and the establishment of a long range vision and needs assessment for transit and transit planning in the region. While these plans are not specifically concerned with ITS applications, they are concerned with improving transit services and increasing efficiency.

CURRENT AND PLANNED ITS APPLICATIONS IN THE GRAND RAPIDS AREA

There are a number of activities being conducted in the Grand Rapids area that could be classified as ITS projects. These projects are discussed below.

Computerized Traffic Signal System

The City of Grand Rapids has operated a computerized traffic signal system for many years and is in the process of upgrading the intersection control equipment and the central computer equipment using Congestion Mitigation and Air Quality (CMAQ) funds. The signal system is unique in several ways. The first is the multi-agency agreement under which the signal system was implemented and continues to operate. Virtually all signals within the Grand Rapids area are operated and maintained by the City of Grand Rapids, regardless of the signal location. This arrangement has proved to be beneficial to the smaller jurisdictions as it provides them with a higher level of service than they might be able to provide if they were acting alone. By implementing and operating the system on a region-wide basis. the users of the system benefit due to a lack ofjurisdictional boundary disruptions that are common in most areas.

The other unique feature of the signal system is its use of the local cable television coaxial cable network for the system interconnect. Grand Rapids is one of only a few municipalities in the country that has been successful in negotiating access to the cable TV network for traffic signal control. As the City upgrades the signal system it also plans to expand the coverage of the system so that eventually all signals in the Grand Rapids area will be connected to the central computer system.

Having the capability to quickly change signal timing patterns from a central location offers significant opportunities for regional traffic management. TCI, the local cable TV company is planning to modify their cable plant from a coaxial system into a fiber optic system. The time frame for this upgrade has yet to be finalized, but if this change occurs there will a significant opportunity to use this network for the transmission of video, data, and other information between the numerous agencies within the study area.

Variable Message Signs

There are presently two variable message signs in the northbound direction and two in the southbound direction in advance of the S-curve on US- 131. The signs currently utilize flip-disk reflective display technology. The signs were installed by MDOT and are controlled by the City of Grand Rapids Police Department. The signs are used to provide traveler information on roadway conditions and to warn of potential hazards and congestion in the S-curve. MDOT is looking to upgrade the signs with new display technology, such as LED or fiber optic displays.

Highway Advisory Radio

A highway advisory radio (HAR) system is currently in operation in the Holland area. The system is used to provide information during summer festivals, and can also be used to warn drivers of inclement weather.

Public Transit

There are several programs and activities within the Grand Rapids area that could be considered applications of ITS user services.

Car/Vanpooling

GRATA provides assistance to individuals and organizations in arranging shared rides through the RIDEFINDER program. Through this program, GRATA facilitates car-pool arrangements, forms vanpool groups, provides vans through the MDOT program MichiVan, and provides information on park and ride lots and bus routes. This represents an application of the Demand Management and Operations user service.

Paratransit

GRATA manages and oversees GO! Bus, special transportation for seniors and persons with disabilities who meet eligibility guidelines. This is a door-to-door service based on advance reservations from users. The service offers lift-equipped vehicles and driver assistance for the needs of the passengers. Both drivers and vehicles are provided by three private transportation carriers under contract with GRATA. The contractors are Calder City Transportation, Yellow Cab and Hope Network. This may be considered an application of the Public Transportation Management user service.

Electronic Information Display

GRATA previously provided this type of information at major transfer stops (those with shelters). It was discontinued because the information changed frequently and could not be kept current. GRATA is considering reinstating this service.

Traffic Information

Traffic information is currently provided on television and on the radio, as well as in the newspaper. Newspaper reports include information about lane closures, construction and other planned events. MDOT provides weekly updates on construction activities to the newspapers. Radio and television reports often provide current information not only about construction, but also about incidents, congestion, and alternate routes. WZZM-TV provides hourly travel information, primarily about weather conditions, but also identifies major accident locations. This is typically limited to the freeway system. The source of information is generally Michigan State Police, local law enforcement departments and an ever increasing use of cellular telephone calls. Similar reports are provided by WCUZ and WOOD Radio. The area has developed a single telephone number that is used for providing information to all television and radio media. This system is known as GRAIL, Grand Rapids Area Information Link.

The information currently provided via radio and television traffic reports may be considered an application of En-Route Driver Information, Route Guidance, and Pre-trip Travel Information ITS user services. Information regarding construction activities and lane closures provided in the newspaper may be considered an application of Pre-trip Travel Information ITS user service.

Emergency Vehicle Signal Pre-Emption

Emergency vehiclesignal pre-emption allows emergency vehicles to get preferential treatment at traffic signals. Opticom signal pre-emption is currently provided at close to 100 intersections for fire vehicles in the metropolitan area. Signal pre-emption for emergency vehicles is considered an application of Emergency Vehicle Management ITS user service.

Automatic Vehicle Location (AVL)

There are two (2) trucking companies in Grand Rapids that are known to utilize AVL technologies. Gainey Transportation Services and Van Eerden Trucking have AVL capabilities through satellite providers. Meijer, Inc. plans to implement AVL in their fleet this year (1996).

Incident Management

Incident management has been provided in the Grand Rapids area primarily through close working relationships and cooperation among the numerous jurisdictions responsible for incident response and clearance. An Incident Management Plan has been developed for the I-96 corridor which calls for the implementation of static trailblazers and fold down signs to facilitate traffic diversion around incidents. Funding to implement these recommendations has yet to be obtained however. As part of the Grand Rapids ITS Early Deployment Study, a similar Incident Management Plan is being developed for the US- 131 corridor.

Weigh-in-Motion

The Sixth District of the Michigan State Police presently utilizes weigh-in-motion technologies, which are permanently located at I-196 and Fuller Avenue, and at the Kent and Montcalm County line. These weigh-in-motion stations are used by both MDOT and the State Police. The police use the stations as screening devices and are very happy with the results. They are also in favor of the expanded use of the technology for enforcement purposes.

SYSTEM CHARACTERISTICS

Traffic Volumes

Traffic volumes on the freeways are shown in Figure 2-2 and on major arterials in Figure 2-3. Traffic volumes shown are the most recently published annual daily traffic (ADT) values for each of the major roadways indicated.

Note that the US 131 expressway has traffic volumes over 100,000 vehicles per day. The highest volume occurs between the Market Street interchange and the I-196 interchange. The ADT at this location is 125,000 vehicles per day. On the other expressways, the highest volumes range from 80,000 vehicles on I-196 just west of the I-196/I-96 interchange to 98,000 vehicles on I-96 between the US 131 interchange ramps. Higher volumes such as these result in recurring congestion when demand exceeds capacity. Furthermore, incidents on these high volume facilities may be expected to result in greater delay due to the large number of vehicles affected.

The same can be said for the arterial sections. Where the volumes exceed the capacity of the highway, recurring congestion and increased delay will develop. Referring to Figure 2-3, the arterials with the highest volumes are 44th Street, Route M-l1 (28th Street) and Plainfield Avenue (Route M-45 connector). The highest volume on 44thStreet is 55,000 vehicles around the US-131 interchange, Route M-l1 has 48,000 vehicles just west of the US 131 interchange and Plainfield Avenue has 41,000 vehicles at the I-96 interchange.

Recurring Congestion

Criteria for quantifying congested areas was developed based on past experience with similar project areas and the *Highway Capacity Manual*, *Special Report* 209 by the Transportation Research Board. The criteria shown in Figure 2-4 establishes maximum ADT per lane for freeways (15,000 vehicles/lane), divided arterials (10,000 vehicles/lane), and two-way undivided arterials (7,500 vehicles/lane). A correlation between the high ADT segments and congested segments can be seen.

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

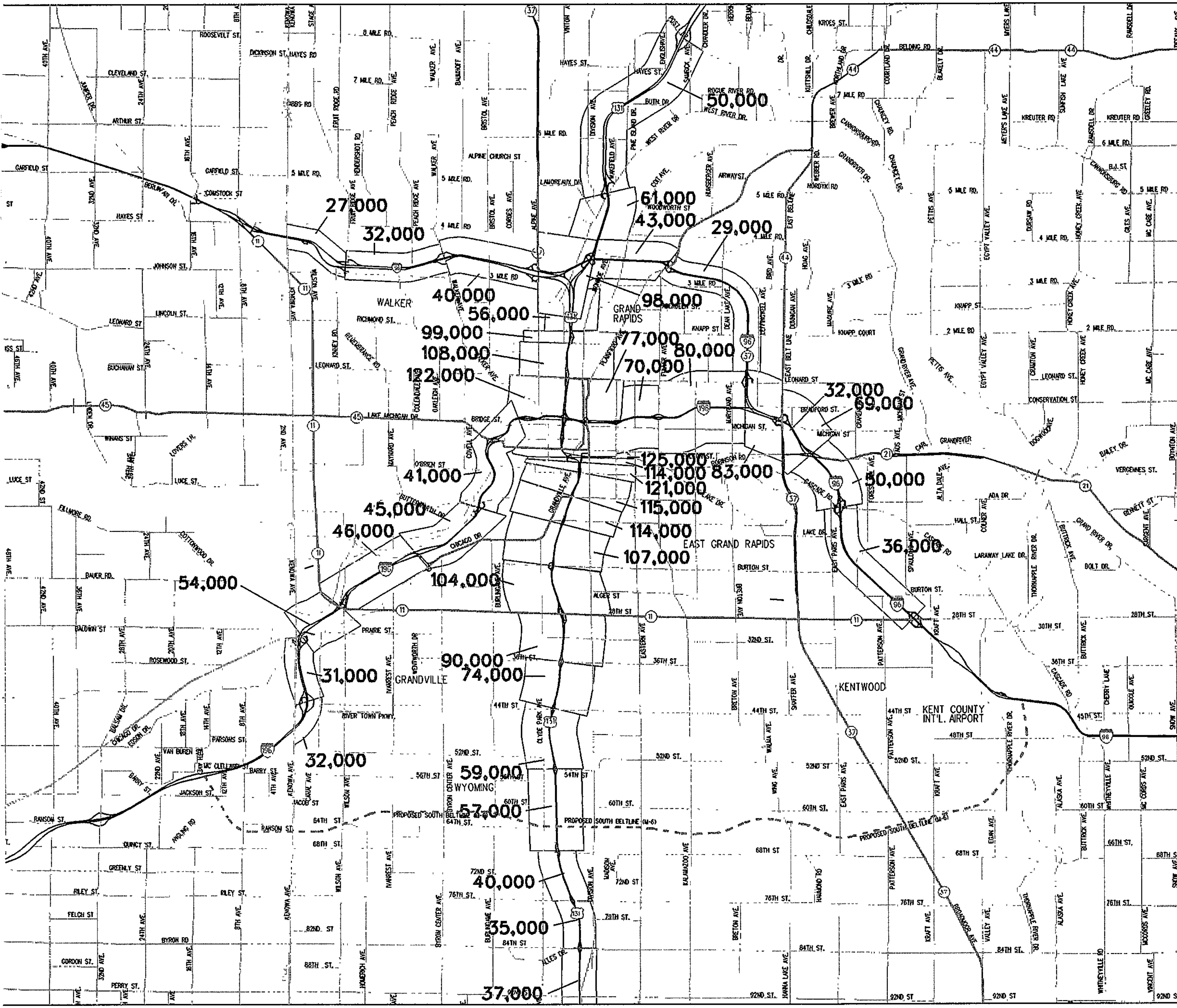


FIGURE 2-2

EXISTING TRAFFIC VOLUMES
ON FREEWAY FACILITIES

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

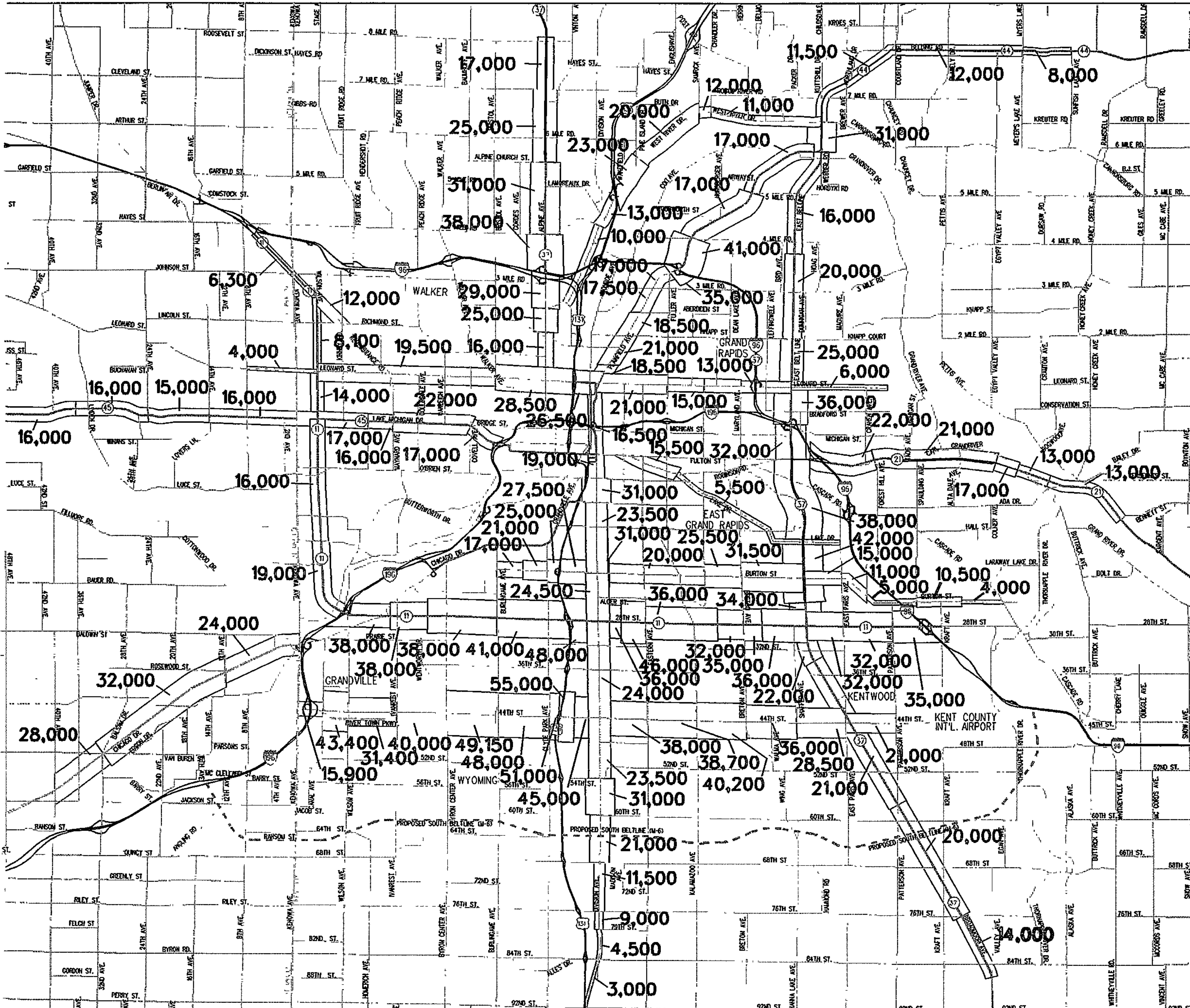
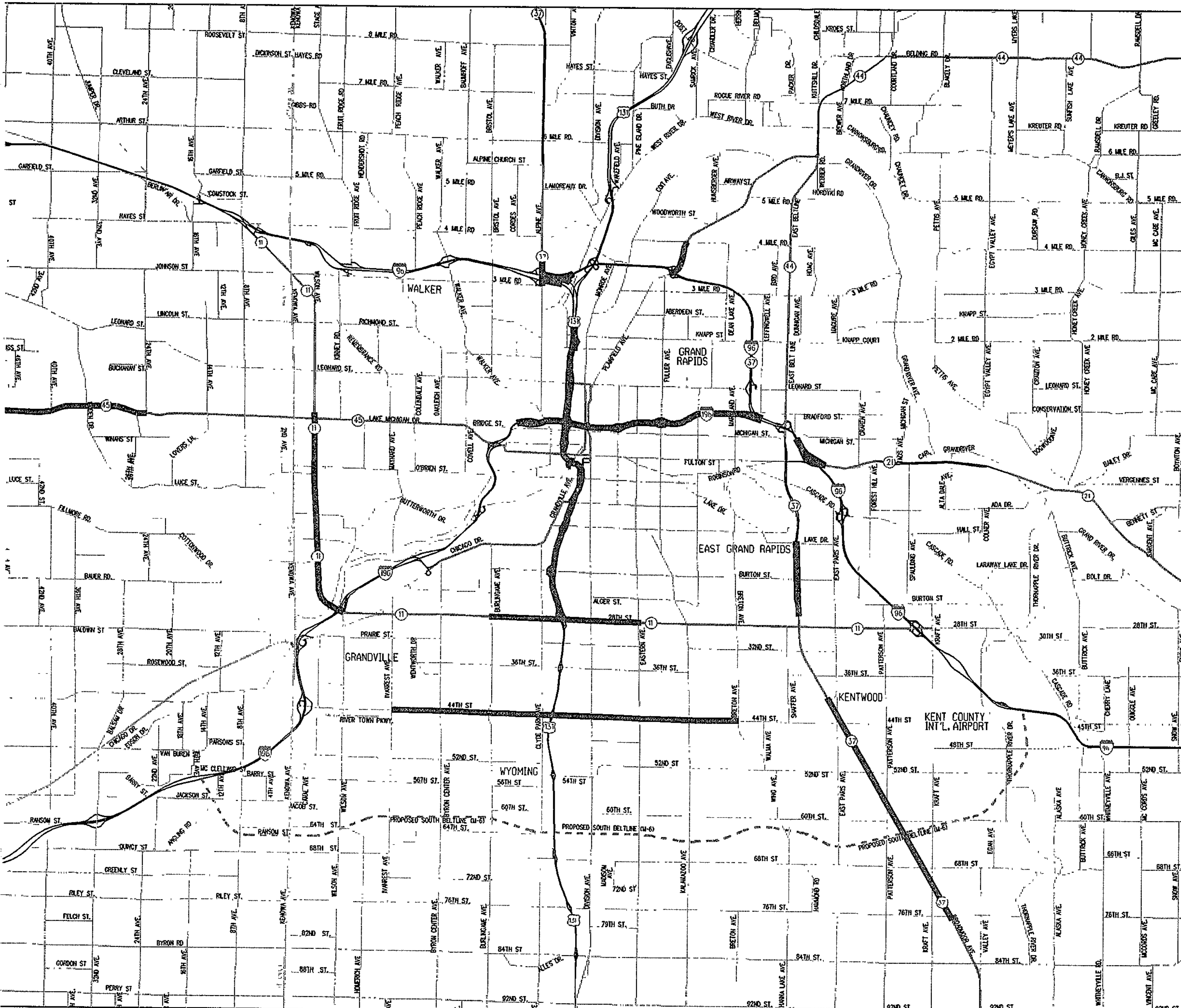


FIGURE 2-3

EXISTING TRAFFIC VOLUMES
ON ARTERIAL FACILITIES



MICHIGAN DEPARTMENT OF TRANSPORTATION

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

LEGEND

ADT/ LANE > 15,000 FREEWAYS
10,000 DIVIDED ARTERIALS
7,500 TWO-WAY UNDIVIDED ARTERIALS

FIGURE 2-4

RECURRING CONGESTION AREAS

Please note that Route M-37 is under construction for capacity improvements. While this will improve the recurring congestion in this area, the improvement will not be permanent.

Facilities that exhibit recurring congestion, as exhibited in Figure 2-4, are especially of interest if demand for the facilities is expected to increase. Based on the GRETS and Grand Valley Metropolitan Council's *2015 Long Range Transportation Plan for the Grand Rapids Metropolitan Area,* the rate of trip making is expected to increase 3 1% from the 1990 levels to 2015. If this is to be the trend over the Grand Rapids roadway network. US 131 and Route M-l1 (28th Street) are of particular concern. US 131 is currently experiencing ADT well over 100,000 vehicles through much of its length through the downtown area (north of Route M-l1 and south of I-96) and is experiencing congested conditions. Route M-l1 along Wilson Avenue and 28th Street is an arterial with signalized intersections and ADT's over 35,000 vehicles throughout much of its length between I-196 and Route M-37 (East Belt Line).

Accidents

Accident rates for the freeway facilities and the major arterials are shown on Figures 2-5 and 2-6, respectively. The rates are expressed in terms of the number of accidents per 100 million vehicle miles traveled. The accident rates were provided by MDOT in the 1993 Highway Sufficiency Database.

The number of accidents per year for each freeway and arterial segment are illustrated in Figures 2-7 and 2-8, respectively. Please note that the range in the number of accidents differs from the freeway sections to the arterial sections in the legend of each figure. This is due to the fact that the number of accidents is typically higher on the arterials with at grade intersections than on the access controlled freeways. Some segment lengths for the arterials also tended to be longer than the freeway segments. This resulted in greater numbers of accidents for some arterial segments than freeway segments since they covered a wider area.

Freeway Accidents

The accident rates illustrate the high frequency accident locations along the roadway network. The highest accident frequency occurs on the approaches to the I-196KJS 131 interchange and US 131 south of the interchange, especially within the US 131 "S-Curve".

Arterial Accidents

Accident rates along arterials are expected to be higher in magnitude since there is limited access control and at grade intersections. The highest accident rates for the arterials occur along the southern leg of Route M-l1 (28th Street), Plainfield Avenue (Route M-44 Connector), Route M-45 (Lake Michigan Drive) within the Route M-l1 loop, and Route M-37 (Alpine Avenue) in the vicinity of the I-96 interchange.

Accidents and Congestion

It was noted during the agency interviews that most of the congestion experienced in the Grand Rapids area is incident related. A similar methodology used in quantifying recurring congestion was used to quantify the locations of the incident related congested areas. In this case. the effects of accidents on the capacity of the highway network is taken into account. The criteria established is a maximum 12,000 ADT/lane with a minimum 7 accidents/lane mile for freeways, 8,000 ADT/lane with 11 accidents/lane mile for divided arterials, and 5,000 ADT/lane with 14 accidents/lane mile for two-way undivided arterials. Figure 2-9 shows the extent that incidents may effect the roadway network. Note that this figure indicates areas that are sensitive to disruptions in the traffic flow and may be congested due to those disruptions.

As discussed in Chapter 2 and as illustrated in Figure 2-9, the Route M-l 1 arterial along 28th Street is especially sensitive to incidents. This makes it inadvisable to suggest using Route M-l 1 as an alternate route since it may cause motorists to experience greater delay, or at worst, expose them to a hazardous situation.

Arterial Signal Systems

The existing signal system is shown in Figures 2-10 and 2-l 1. All of the traffic signals in the area are maintained by the City of Grand Rapids, and will be upgraded to Eagle EPAC controllers under a three-year program funded with Congestion Mitigation and Air Quality (CMAQ) funds. The system being implemented is a centralized PC based system, which will be capable of vehicle and pedestrian detection. Local agencies will have the capability to access the system and observe signal operations, however, the communications system to be used within the system has yet to be finalized. There are also plans to use video surveillance on a limited basis.

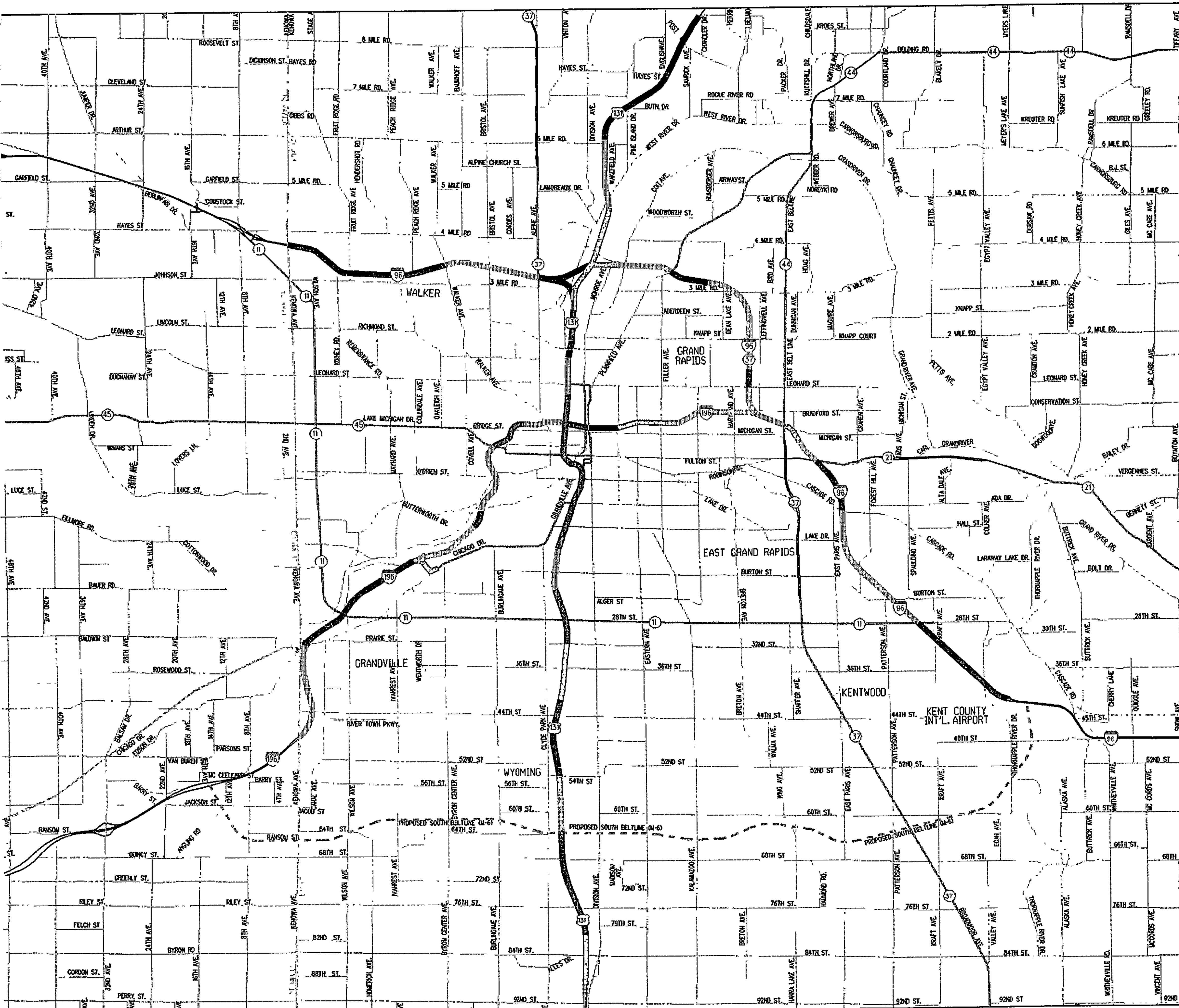
The planned hardware upgrades will enhance the capabilities of the arterial system and will provide up to date traffic data, which some operating agencies have indicated as a priority. These upgrades may also have a positive impact on the feasibility of utilizing the arterials as alternate routes.

Transit Ridership/Routes

Transit routes provided by GRATA are shown in Figure 2-12. These routes have been in effect since the downtown interim transit center opened on November 27, 1995. The restructured route network attempts to provide improved service by eliminating unproductive routes; providing consistent headway times; providing convenient transfer points; implementing new Circulator Routes, Service Routes and Commuter Express Routes; revamping the Saturday service; and extending the evening service. The GO! Bus service and Rideshare programs have also been revised in order to generate more riders and to improve service efficiency.

MICHIGAN DEPARTMENT OF TRANSPORTATION

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

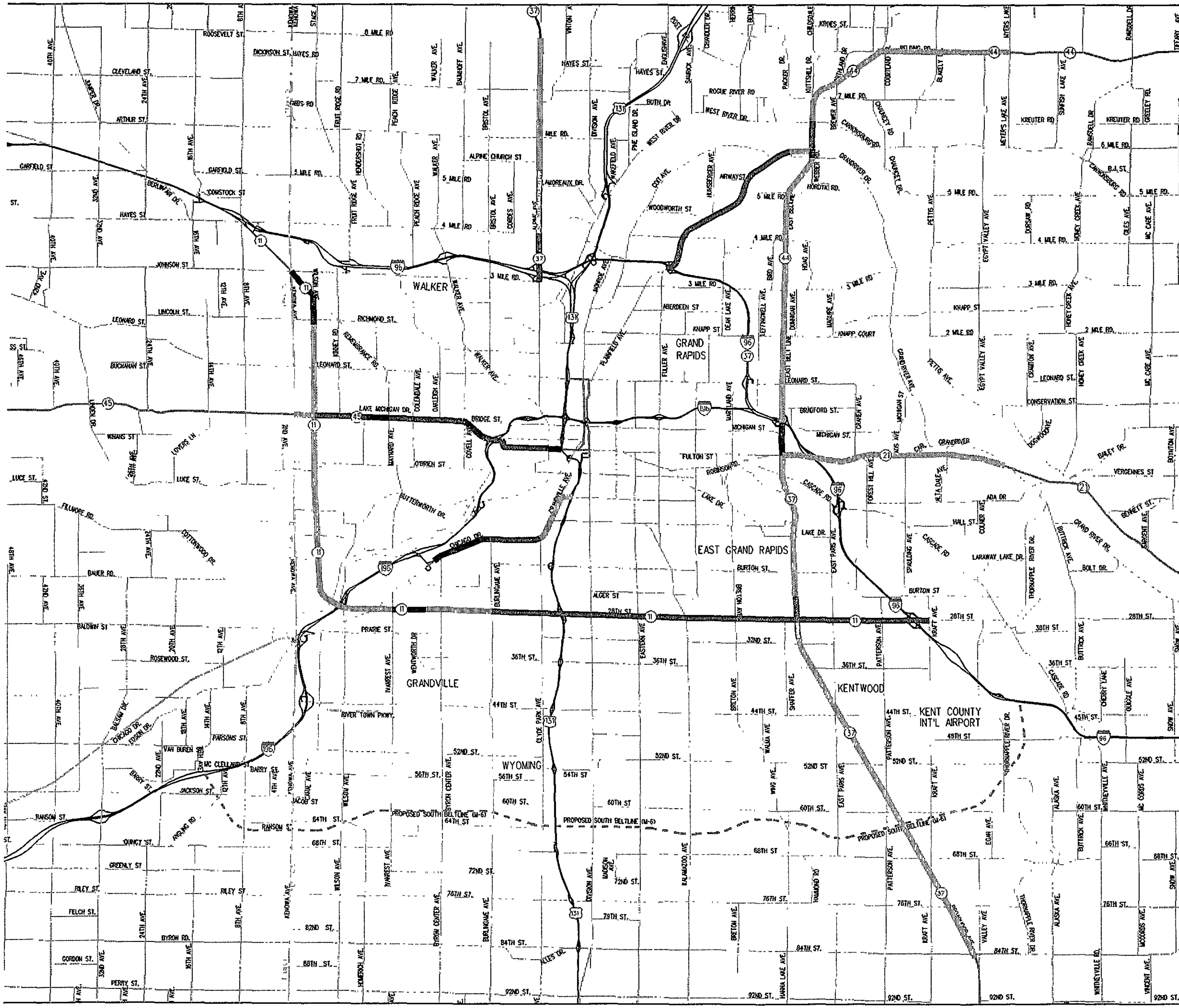


LEGEND

- LESS THAN 100 ACCIDENTS PER 100 MVM
- 100-200 ACCIDENTS PER 100 MVM
- 200-300 ACCIDENTS PER 100 MVM
- 300-400 ACCIDENTS PER 100 MVM
- GREATER THAN 400 ACCIDENTS PER 100 MVM

MVM - Million Vehicle Miles

FIGURE 2-5
ACCIDENT RATES - FREEWAY FACILITIES



MICHIGAN DEPARTMENT OF TRANSPORTATION

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

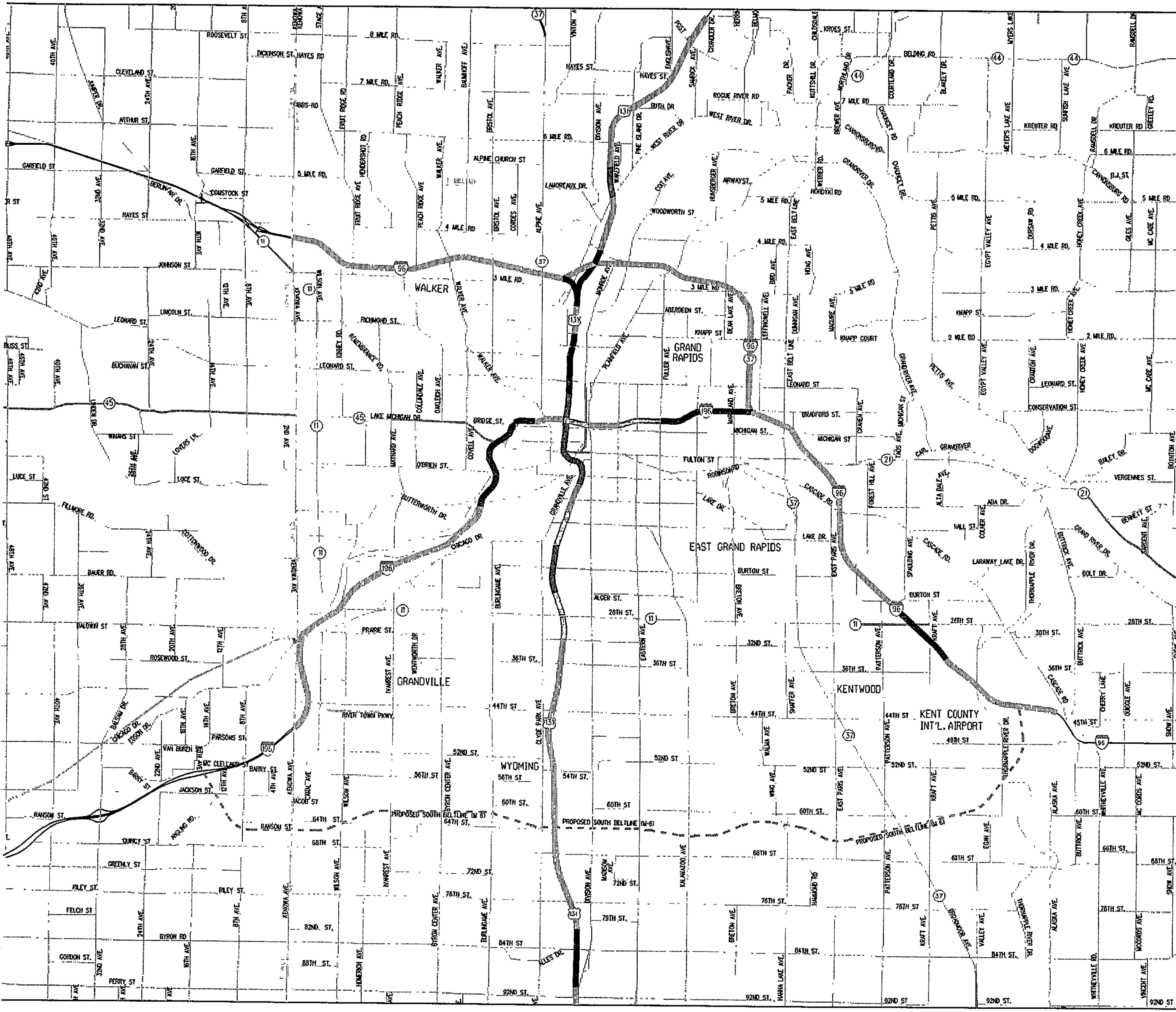
LEGEND

- LESS THAN 500 ACCIDENTS PER 100 MVM
- 500-600 ACCIDENTS PER 100 MVM
- 600-700 ACCIDENTS PER 100 MVM
- 700-800 ACCIDENTS PER 100 MVM
- GREATER THAN 800 ACCIDENTS PER 100 MVM

MVM - Million Vehicle Miles

FIGURE 2-6
ACCIDENT RATES - ARTERIAL FACILITIES

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN



LEGEND

- LESS THAN 20
- 20-30
- 30-40
- 40-50
- GREATER THAN 50

FIGURE 2-7
NUMBER OF ACCIDENTS PER YEAR (1993) - FREEWAY FACILITIES

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

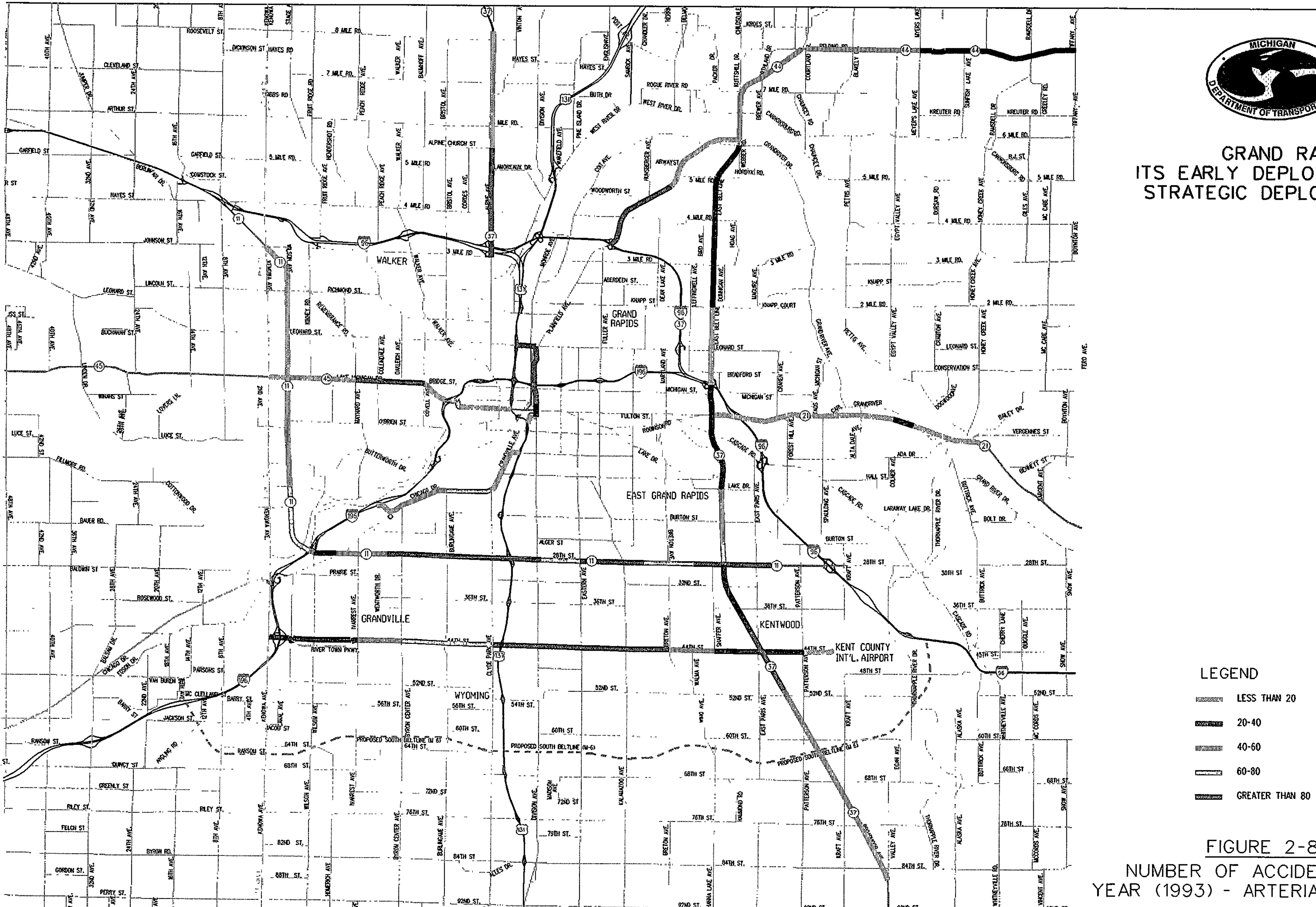
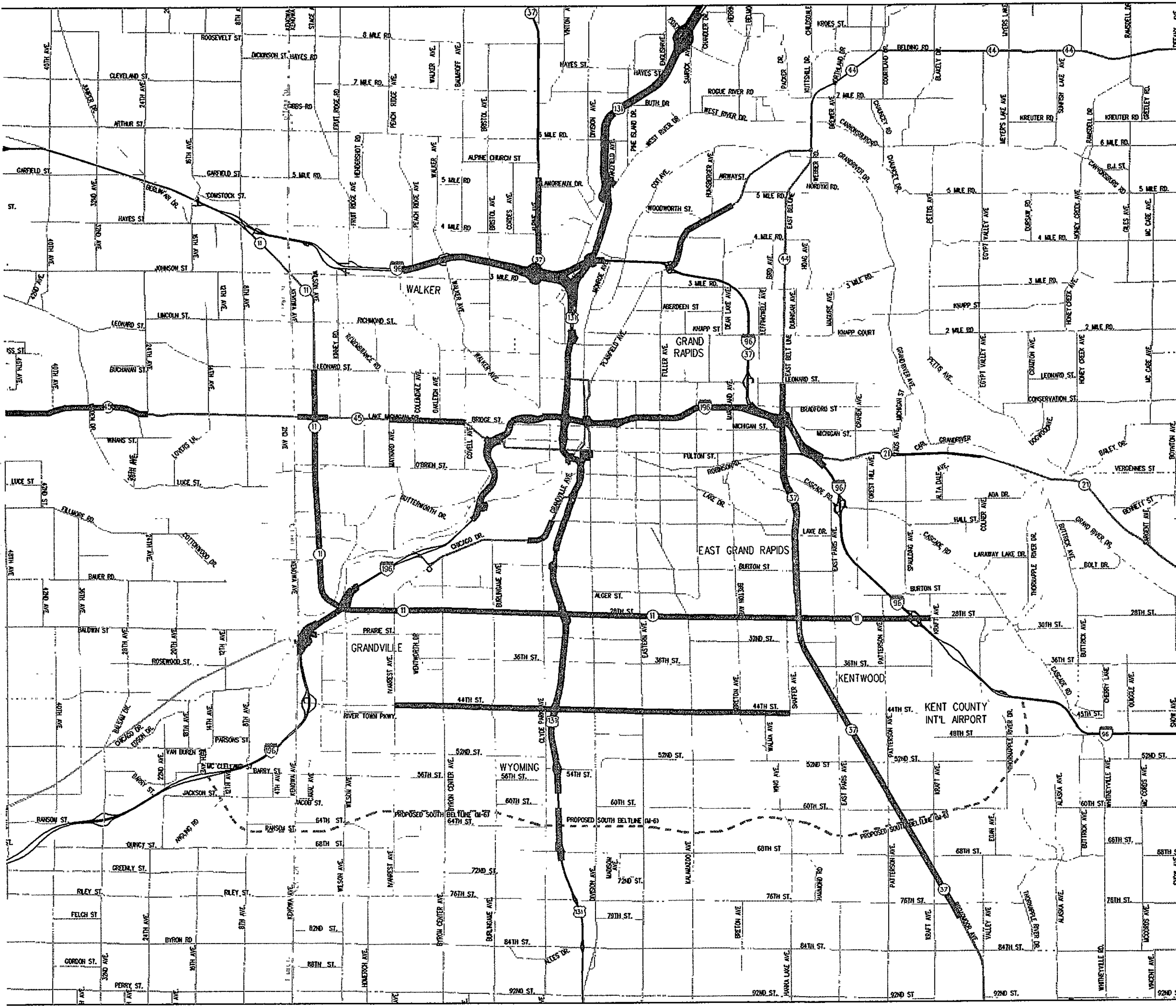


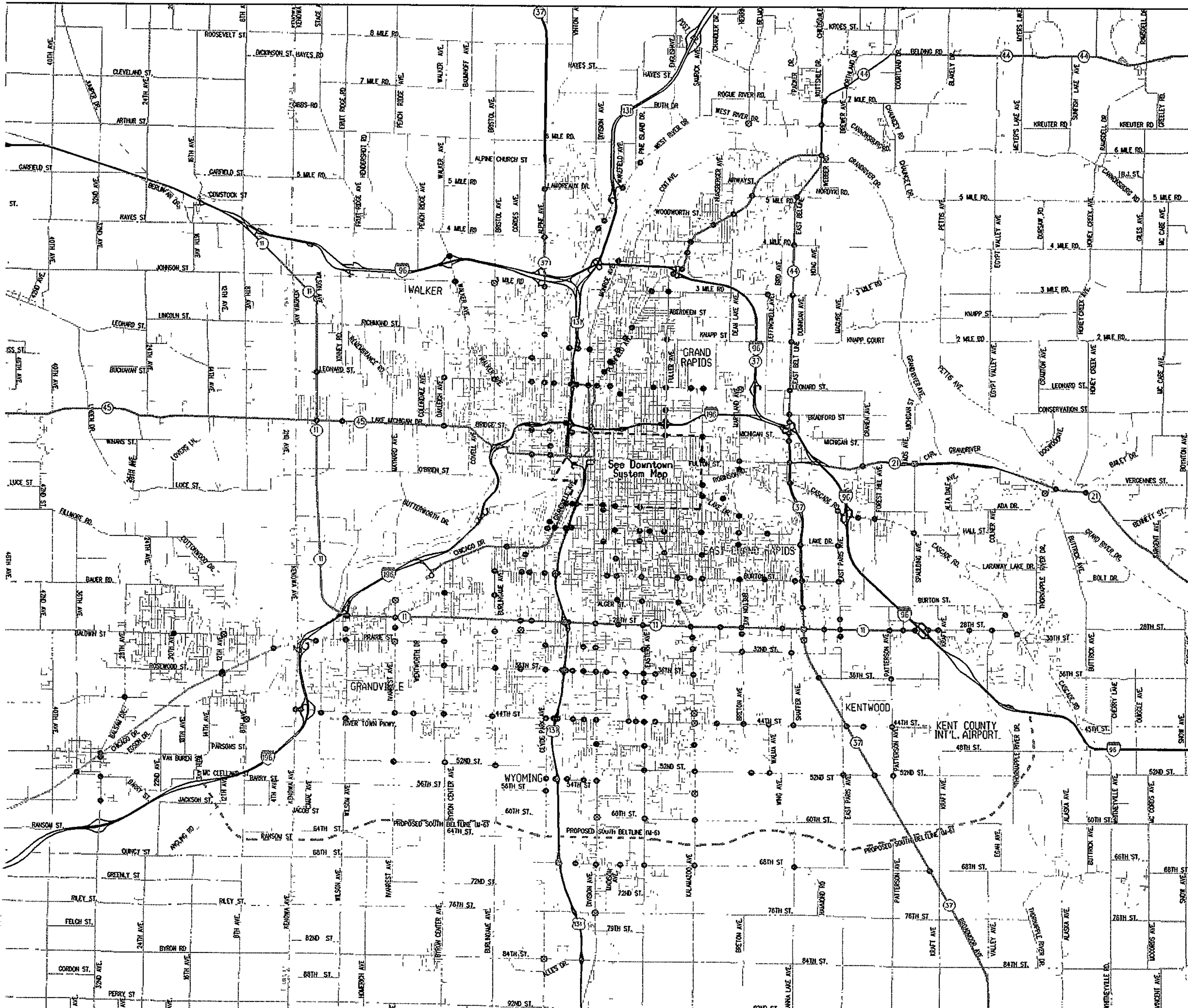
FIGURE 2-8
NUMBER OF ACCIDENTS PER YEAR (1993) - ARTERIAL FACILITIES



GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

FIGURE 2-9
CONGESTION AREAS DUE TO ACCIDENTS

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN

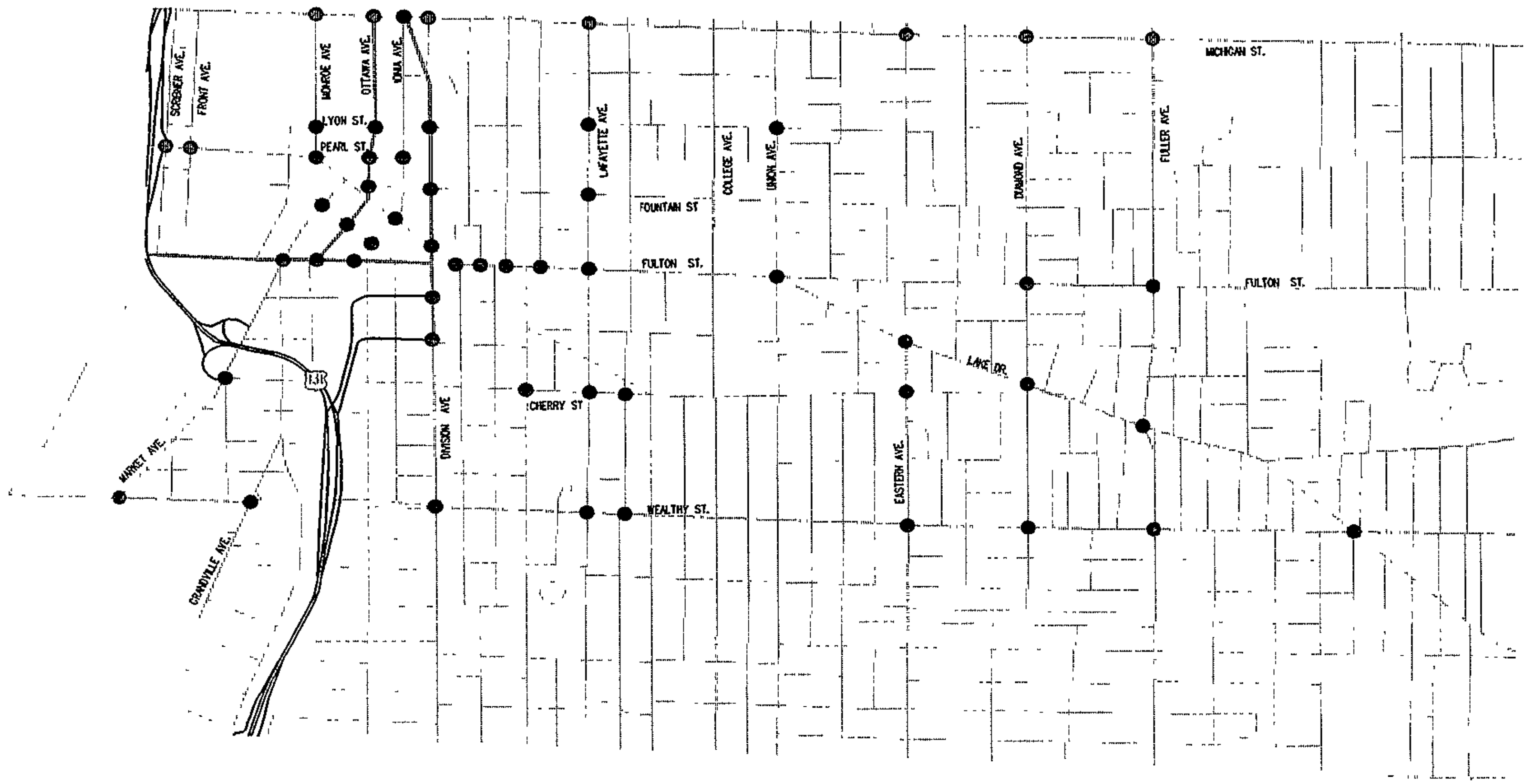


LEGEND

- TIME BASED COORDINATION SIGNAL
- CENTRALLY CONTROLLED SIGNAL
- FREE OPERATING SIGNAL

FIGURE 2-10
TRAFFIC SIGNAL SYSTEM

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN



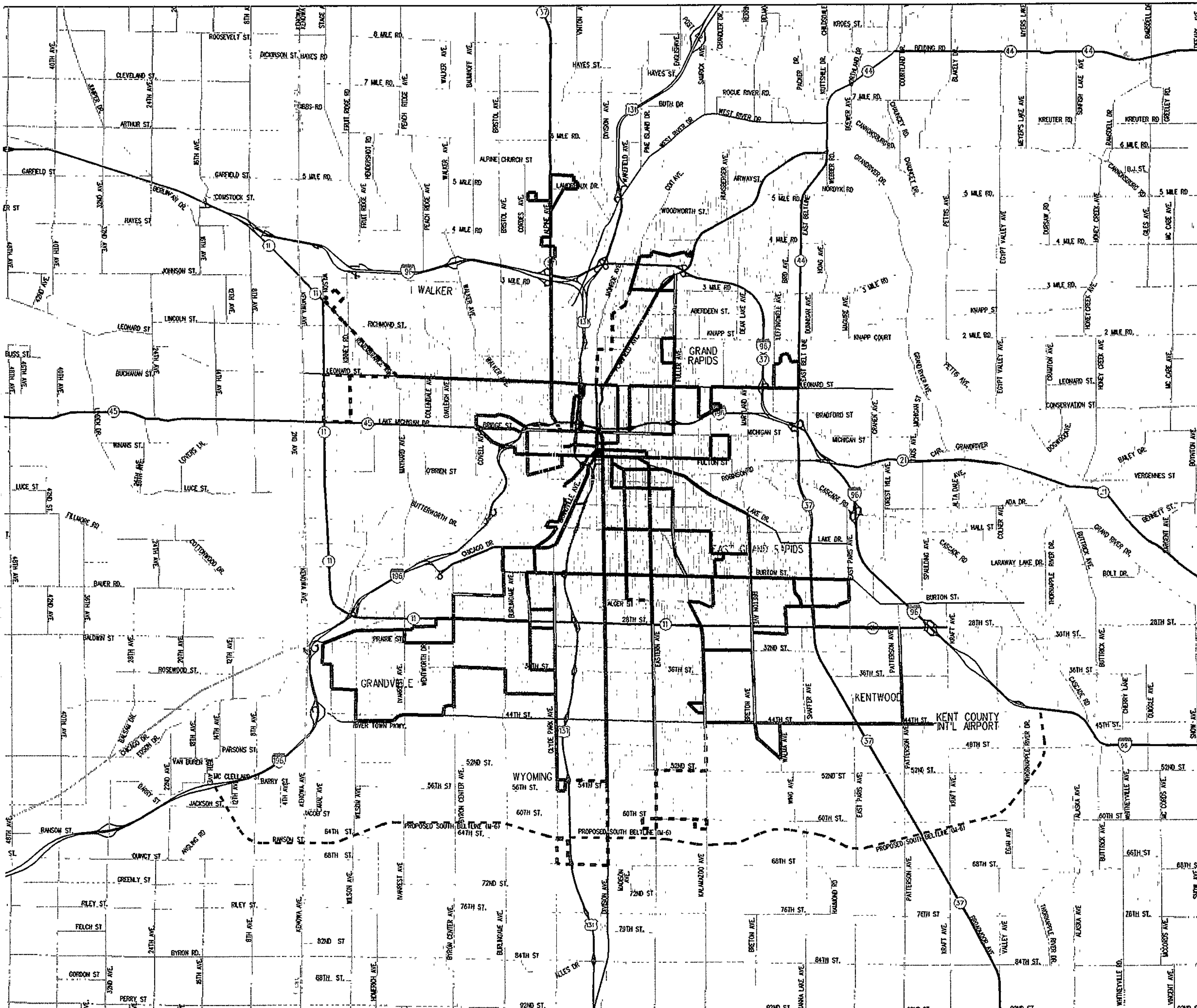
LEGEND

- TIME BASED COORDINATION SIGNAL
- CENTRALLY CONTROLLED SIGNAL
- FREE OPERATING SIGNAL

FIGURE 2-11

TRAFFIC SIGNAL SYSTEM
DOWNTOWN AREA

GRAND RAPIDS
ITS EARLY DEPLOYMENT STUDY
STRATEGIC DEPLOYMENT PLAN



LEGEND

Transit Route
Limited Service Route

FIGURE 2-12
GRATA TRANSIT ROUTES

INSTITUTIONAL CHARACTERISTICS

The Grand Rapids Metropolitan area encompasses a number of jurisdictions and affected agencies. This may complicate institutional issues by increasing the number of involved jurisdictions and agencies that must be involved in any endeavor that affects the entire area. Also, the jurisdictions and agencies operate independently, resulting in a variety of policies.

Opportunities

There are a number of activities and organizations in the metropolitan area that foster interagency communication and cooperation. These activities and organizations can contribute to the successful implementation of this plan by acting as a source of information and feedback, as well as a foundation for further institutional communication and cooperation.

Incident Management Activities

Activities are currently underway to develop an incident management plan for US 131 as part of this study. The system will provide basic guidelines for all agencies involved in incident management activities. Although incident management programs vary from region to region, all address the following general elements incident detection, verification, response, removal, traffic management, and motorist information. Information about these elements will be included in the Incident Management Plan, which addresses everything from contacts for agencies to pre-planned alternate routes.

Since much of the delay in the Grand Rapids area is due to accident related congestion rather than recurring congestion, Incident Management is expected to have a significant impact on delay. The foundation for successful incident management is apparently in place since the agencies involved in incident management noted that there typically has been good cooperation among the agencies responding to an incident. However, there is the potential to realize benefits from enhanced coordination and communication if an interagency plan for all activities at the incident site was enacted. Furthermore, the development of an incident management program would provide agencies with a better understanding of the ramifications of one agency's activities on other agency activities.

To further enhance incident management, a proposed State Police Regional Dispatch Center will be located in a new complex that will be built across from the White Caps baseball stadium. This building will house the Sixth District State Police headquarters. This would be an appropriate location for the future area-wide traffic management center (TMC). Locating the TMC in the same building as the regional dispatch would enhance coordination and communication between the emergency response and traffic operations activities.

Funding

Potential funding sources for elements of the ITS Early Deployment Plan vary, depending on the user service and on the specific project. Potential funding sources may include federal funding, including National Highway System funding, Surface Transportation and Congestion Mitigation and Air Quality (CMAQ) funding; state funding; and local funding, including funds from counties and cities. Also, some projects may present the opportunity for funding from private entities, through joint ventures and other public/private partnerships. as well as through consumer driven technologies such as technologies that will be integrated into the automobile (for example, anti-collision devices and route guidance devices).

Institutionalization Of Early Deployment Plan

It is recommended that the ITS Early Deployment Plan be institutionalized. This is recommended not only with the hope that it would then have an advocate and a mechanism for implementation, but also because the document is intended to be a living document, one which will require modification and re-interpretation as local circumstances change and as technology advances and new technologies become appropriate for implementation. Because the plan encompasses multiple jurisdictions, it may be institutionalized as a regional entity, such as the Grand Valley Metropolitan Council.

Chapter 3
ITS USER SERVICES

AGENCY PERCEPTIONS OF LOCAL APPLICABILITY OF ITS USER SERVICES

Twenty-nine ITS user services have been identified by the Federal Highway Administration (FHWA). The 29 user services identified by the FHWA have been grouped into seven (7) "bundles", each of which represents the application of advanced technology to a specific transportation function. The seven (7) bundles of user services are:

- Travel and Transportation Management.
- Travel Demand Management.
- Public Transportation Management.
- Electronic Payment.
- Commercial Vehicle Operations.
- Emergency Management.
- Advanced Vehicle Safety Systems.

The following sections discuss the bundles of user services, and provide a brief description of each user service[4], as well as a discussion of its applicability to the Grand Rapids area. Each user service is discussed in the context of how it would potentially enhance the efficiency or capability of the transportation system, and how it would help meet the needs identified by the various users of the transportation system.

TRAVEL AND TRANSPORTATION MANAGEMENT

The Travel and Transportation Management bundle includes six user services that are designed to use advanced systems and technologies to improve the safety and efficiency of the transportation system, and to provide motorists with current information about traffic and roadway conditions, as well as traveler services. The user services in the Travel and Transportation Management bundle are shown in Table 3-l and discussed in greater detail in the following sections.

Local Applications of Travel and Transportation Management User Services. In general, the user services in this bundle, with the exception of emissions testing and mitigation, are identified as most appropriate for application in the Grand Rapids area because they facilitate management of the transportation infrastructure. En-route driver information, route guidance, and incident management were most often identified as appropriate by the agencies interviewed. These user services were identified as appropriate because they facilitate utilization of all available capacity, and enhance safety. It was also noted that implementation of these user services first would allow motorists to see the positive impact of ITS, and would facilitate their support of other user services, such as those that enhance transit and demand management.

4 Information on the user services was obtained from the *National ITS Program Plan, Intelligent Transportation System, edited* by Gary W. Euler and H. Douglas Robertson, March 1993.

Table 3-l Travel and Transportation Management User Services

Bundle	User Services
Travel and Transportation Management	En-Route Driver Information Route Guidance Traveler Services Information Traffic Control Incident Management Emissions Testing and Mitigation

En-Route Driver Information

The en-route driver information service provides motorists with information about traffic and roadway conditions due to both scheduled activities (such as construction or special events) and unscheduled activities (such as accidents). Driver information may be provided via radio, variable message signs (VMS), or in-vehicle signing.

Local Applications for En-Route Driver Information. En-route driver information was identified as an appropriate user service for implementation in the short term by many of the agencies interviewed. The applicability of en-route driver information is demonstrated by the existing Variable Message Signs and advisory speed limit signs on US- 131. These signs are operated by the Grand Rapids police, who select the message to be displayed from a number of messages that have been approved by Michigan Department of Transportation (MDOT). MDOT said that the signs may be replaced in near future. When they are replaced they will be relocated farther from the S-curve to provide drivers with additional warning. Currently, congestion extends beyond the signs. so that drivers get to congestion before they are provided with a warning via the VMS. MDOT currently uses portable VMS's during large construction projects and for special events.

En-route driver information is also currently provided through private companies in the Grand Rapids area. For example. Skyview Traffic provides information to 14 radio stations; two or three of these stations provide traffic updates continuously.

Local agencies noted that expansion of the provision of en-route driver information would be useful not only during congestion caused by accidents, but also to provide information to motorists for special events, such as local and regional festivals. One agency noted that Holland, Michigan has successfully implemented a highway advisory radio (HAR) system, which is used to provide information during summer festivals, and can also be used to warn drivers of inclement weather in the winter.

The need for driver information in the Grand Rapids area is also demonstrated by the experience of the Sixth District of the State Police. The Sixth District used to provide weather information to people, however, the response was so overwhelming that people are now discouraged from calling the Sixth District. so that adequate phone lines can be maintained for emergency calls.

The State Police now disperse the information to radio and television stations, and through the "800" phone number in Lansing.

Route Guidance

The route guidance service provides motorists with a suggested route to reach their destination, along with instructions for upcoming turns or other maneuvers. Ultimately, a route guidance system would provide travelers utilizing all modes with directions to their destinations based on real-time information about the transportation system, including lane closures, traffic conditions, and transit information.

Local Applications for Route Guidance. Although some agencies felt that the volumes on most facilities do not warrant intervention, other agencies thought that route guidance information would be valuable, particularly following an incident. In fact, route guidance was a component of the incident management plans for I-96 and US-31. The signs marking the alternate route were installed in accordance with the incident management plan for US-3 1, however, the signs marking the alternate route were never implemented for I-96.

Currently, route guidance information is sometimes provided by radio stations, although one agency noted that the routes suggested are not always appropriate. In other cases, there are a lack of alternate routes. For example, there are a limited number of routes to the shoreline (M-45, US-31, and M- 104) and all experience delay. In Ottawa County there is a lack of river crossings which significantly impact traffic whenever an incident occurs on one of the crossings. In general, however, route guidance is recognized as a user service appropriate for implementation in the short term.

Traveler Services Information

Traveler services provides the traveler with information regarding local services and facilities, and has been compared to a computerized version of the "yellow pages". This information would be available for pre-trip planning via a terminal in the home, office or hotel. This information would also be available en-route via either a terminal in the vehicle or at public facilities such as highway rest stops or transit terminals. Information regarding the location, services or amenities, and operating hours would be available for a variety of goods and services, including food, lodging, parking, auto repair, hospital and medical, and police stations. This service would also allow the traveler to communicate with service providers interactively, which would allow travelers to reserve or confirm vacancies or services.

The type of information provided would vary depending on whether the information is accessed at a fixed location (such as a hotel lobby or transit center), or en-route (such as in a transit vehicle, private auto. or commercial vehicle). The type of information and method of presentation would also vary. Information presented to drivers while the vehicle is in motion would be restricted for safety reasons; when the vehicle is parked, the driver would be free to access and utilize all available information.

Local Applications for Traveler Services Information. Traveler services information was generally identified as appropriate for implementation in the medium term. While some agencies considered it a very low priority because it did not enhance safety or increase capacity, other agencies thought that was valuable because it would be helpful for visitors. It was suggested that traveler services information should be provided to visitors before they get to the city.

Traffic Control

The traffic control user service focuses on increasing the safety and efficiency of traffic flow on streets and highways. It includes adaptive signal systems on surface streets and freeway control techniques such as ramp metering on freeways.

The traffic control service would gather data from the field, analyze it, and use it to assign right-of-way to users of the transportation system. The goal is to maximize the efficiency of the movement of people and goods through the roadway network, thus it may provide preferential treatment to transit and other high occupancy vehicles (HOV's), if preferential treatment is in accordance with-local objectives and operating policies. The proper implementation of traffic control would help alleviate congestion problems, and improve air quality. The information generated by the traffic control user service can also be disseminated to the general public, and other service providers. laying the foundation for other user services.

Traffic control, which includes surveillance, control, and communications, provides the basis for many of the other user services. The data collected, processed and used by traffic control will be utilized by virtually all of the other services in the Travel and Transportation Management bundle, as well as some of the services in the Public Transportation Operations and Emergency Management bundles.

Local Applications for Traffic Control. Traffic control was considered a priority by almost all of the agencies interviewed. Most of the traffic signals in the area are maintained by the City of Grand Rapids, and are being upgraded to Eagle EPAC controllers under a three-year program funded with Congestion Mitigation and Air Quality (CMAQ) funds. The system being implemented is a centralized PC based system, which will be capable of vehicle and pedestrian detection. Local agencies will have the capability to access the system and observe signal operations, however, the communications system to be used within the system has not yet been finalized. There are also plans to use video surveillance on a limited basis.

The planned hardware upgrades will enhance the capabilities of the arterial system and will provide up to date traffic data. which some operating agencies have indicated as a priority.

Incident Management

The incident management user service focuses on enhancing incident detection and response. Incident detection would be enhanced by advanced sensors, data processing, and communications which would allow officials to quickly and accurately identify a variety of incidents, and would allow immediate implementation of actions to minimize the effects of incidents. The service would also help officials identify and forecast hazardous weather, as well as traffic and roadway conditions so that preventative action can be taken to minimize the consequences of incidents. Incident management also involves activities that minimize the negative impacts of planned events, such as lane closures or special events. Incident management may include coordinating the schedules of construction or other planned roadway activities.

Local Applications for Incident Management. Incident management was identified as appropriate by many of the agencies interviewed. It was deemed beneficial both from the standpoint that it enhances safety and from the standpoint that it increases capacity. In fact, development of an incident management plan for US-131 is a significant component of this study.

Incident management might be expected to have a significant impact on delay. due to the fact that much of delay in the Grand Rapids area is due to incident related congestion, rather than recurring congestion. The foundation for successful incident management is apparently in place, agencies involved in incident management note that there is typically good cooperation among the agencies responding to an incident.

The timely removal of incidents was identified as a major concern for the incidents that might occur on the railroad line that parallels M-21. A railroad accident blocking the tracks could result in the isolation of the Georgetown community, which could have significant impacts because it might prohibit emergency vehicles from easily accessing the area (the only river crossings in the area are at M-45 and Wilson Avenue).

Emissions Testing and Mitigation

Emissions testing and mitigation can be used to provide area-wide pollution information for use in monitoring air quality and providing data to be used to develop strategies to improve air quality. Emission information may be used to re-route traffic around sensitive air quality areas, or even, under severe conditions, to control access to such areas. Other applications include roadside monitoring of individual vehicles to identify vehicles that exceed emission standards; or diagnostic systems that provide in-vehicle monitoring of emissions levels, which would alert the driver of non-compliance so that corrective measures could be taken.

Local Applications for Emissions Testing and Mitigation. Emissions testing and mitigation is not of interest to any of the agencies interviewed. Although the Grand Rapids metropolitan area was originally defined as a non-attainment area, this status has been re-evaluated and is expected to be rescinded in light of the fact that much of the pollution in the area originates elsewhere.

TRAVEL DEMAND MANAGEMENT

The Travel Demand Management (TDM) bundle includes three user services that are designed to reduce congestion on the transportation infrastructure by encouraging commuters to use modes other than the single occupant vehicle (SOV), to alter the time and or location of their trip, or to eliminate a trip. In response to congestion and air quality concerns, many cities have already initiated travel demand management activities, and others will be required to in response to the mandates of the 1990 Clean Air Amendments. The user services in the Travel Demand Management bundle are shown in Table 3-2 and discussed in greater detail in the next sections.

Local Applications for Travel Demand Management User Services. In general, the user services in this bundle. with the exception of pre-trip travel information. are identified as less appropriate in the short term for application in the Grand Rapids area. Because recurring congestion in Grand Rapids is of relatively limited incidence and duration, these user services would be expected to have relatively less impact than would user services that focus more directly on management of traffic flow. The user service of greatest interest in the travel demand management bundle is pre-trip travel information, which could be used to provide information to motorists regarding locations of congestion, incidents. and route selection.

Table 3-2 Travel Demand Management User Services

Bundle	**User Services**
Travel Demand Management	Demand Management and Operations Pre-Trip Travel Information Ride Matching and Reservation

Demand Management and Operations

The demand management and operations user **service** attempts to accomplish three primary goals: reduce SOV travel, particularly SOV commuting: affect a mode change from SOV’s to HOV’s, specifically in certain targeted markets; and provide a variety of mobility options. In an effort to accomplish these goals. demand management and operations may facilitate convenient alternatives to the SOV in an effort to affect a change in mode, such as transit service enhancements, the development and/or improvement of HOV facilities. and the implementation of car-pool and vanpool programs.

This user service may also affect mode choice through travel incentives and disincentives, through controls on the availability, location, and price of roadways and parking. These measures are expected to improve traffic and transit operations, and increase auto occupancies. Alternative work arrangements, such as variable work hours, compressed work weeks. and telecommuting may also be implemented in an effort to manage demand.

Local Applications for Demand Management and Operations. Many agencies thought that demand management and operations would be more appropriate in larger cities, or sometime in the future, when congestion is more significant in Grand Rapids. There are, however, quite a few applications of demand management and operations currently in Grand Rapids. One example is a vanpool program which currently utilizes five to seven vans and serves commuters at some of the larger employers. This vanpool program is funded by the state. Other examples of existing programs and facilities that might be considered a part of the demand management and operations user service include bike routes and pedestrian walkways, parking restrictions downtown, and a parking ordinance that reduces the amount of parking required if vanpool and/or car-pool programs are implemented. A final example of a potential application of the demand management and operations user service is the proposed demonstration project which would utilize 3M’s Opticom system for signal priority for GRATA buses. Although discussions on this project have been held recently, there is no commitment to proceed, and some cities in the area have expressed discomfort with the concept.

Pre-Trip Travel Information

The pre-trip travel information user service provides travelers with information prior to departure, before a mode has been chosen. This information may encourage alternatives to SOV travel, including either an HOV mode or the elimination of a trip. Information about transportation demand management (TDM) pricing strategies may also be available to further encourage alternatives to the SOV. Coordination with electronic payment services (discussed later) would further enhance the capabilities and presumably the effectiveness of the pre-trip travel information.

Pre-trip information includes a range of multi-modal transportation information that may be accessed at home, work, or other major sites where trips originate. Information to be provided may include transit routes, schedules, transfers, fares, intermodal connections, and ride matching services; current traffic and highway conditions, regulations and tolls; information on incidents, accidents, and road construction; current and predicted congestion and traffic speeds on specific routes; parking conditions and fees; availability of park-and-ride facilities, special event information, and weather information.

Local Applications for Pre-Trip Travel Information. Pre-trip travel information is considered appropriate for implementation in the short term by some of the agencies interviewed. This information is valuable because it provides another mechanism for communications with motorists, and can be used to enhance the effectiveness of the provision of the incident management and route guidance user services.

Ride Matching and Reservations

Ride matching and reservations provide a strategy for reducing demand by facilitating and encouraging ridesharing as an alternative to the SOV. This service expands the market for ridesharing by providing real-time ride matching information along with reservations and vehicle assignments.

Under this service, people who wish to rideshare would provide a travel itinerary (date, time, origin and destination) and any specific restrictions or preferences (the need for wheelchair access, mode preference, etc.) to a ride matching service. The traveler would then receive ridesharing options for that itinerary, considering the preferences noted.

Local Applications for Ride Matching and Reservations. Ride matching and reservations is considered appropriate for implementation in the medium term by many of the agencies interviewed. It is expected that this service would have a greater impact when congestion is more significant, which might be expected in the future, because the Grand Rapids area has experienced steady growth, which is expected to continue.

Ride-matching is enhanced by the provision of Carpool parking lots by both GRATA and MDOT (for example at M-44 and I-96, and on US-131 north of I-96). Some agencies noted that the potential for ridesharing is enhanced by the fact that there are a number of large employers in the area, some of whom provide preferential parking for Carpools and/or vanpools.

PUBLIC TRANSPORTATION MANAGEMENT

The Public Transportation Management bundle includes four user services that are designed to utilize advanced vehicle electronic systems to provide data which is then used to improve transit service to the public. The user services in the Public Transportation Management bundle are shown in Table 3-3 and discussed in greater detail in the following sections.

Local Applications of Public Transportation Management User Services. All transit service in the Grand Rapids area is provided by a single transit agency. GRATA. GRATA is currently updating its fleet, and is trying to increase ridership, which has declined in recent years. While some agencies interviewed indicated that the public transportation management user services would be of interest if they would increase transit ridership, in general, many of these user services were identified as more appropriate for implementation in the medium to long term.

Table 3-3 Public Transportation Management User Services

Bundle	User Services
Public Transportation Management	Public Transportation Management En-route Transit Information Personalized Public Transit Public Travel Security

Public Transportation Management

Public transportation management automates the operations, planning, and management functions of public transit systems. It provides real-time computer analysis of vehicles and facilities to improve transit operations and maintenance. The analysis identifies deviations from the schedule and offers potential solutions to dispatchers and drivers. This service will help maintain transportation schedules and assure transfer connections from vehicle to vehicle and between modes and can be coupled with traffic control services to facilitate quick response to service delays. Information regarding passenger loading, vehicle running times, accumulated miles and hours and vehicle maintenance will help improve service and provide managers with a wealth of information on which to base decisions. Service schedulers will have timely data to adjust trips. Personnel management will be enhanced with automatic recording and verification of driving and maintenance task performance. Reports, including management, operations, and Section 15 reports will be prepared with greater efficiency.

Local Applications for Public Transportation Management. Transportation service provided by GRATA includes both regular route bus service and paratransit service. All communication and coordination within the transit system, including dispatching, is currently provided via a 440 MHz radio system. This system is adequate from the perspective that the GRATA fleet can easily accommodate the peak period demand for regular route service. The management of paratransit services is enhanced by a new paratransit scheduling system which was procured in June 1995. This system coordinates paratransit service for the three local providers.

En-Route Transit Information

En-route transit information is provided to travelers using public transportation after they begin their trips. Real-time, accurate transit service information will be available on-board the vehicle, at transit stations and bus stops to assist travelers in making informed decisions and itinerary modifications once a trip is underway.

Local Applications for En-Route Transit Information . En-route transit information may be appropriate for implementation at the transit center which is planned for implementation in the future. An interim transit center was opened in November 1995 at Ionia north of Lyon. A permanent transit center, which is expected to open in approximately five years, will be located near the arena. The proposed transit center will provide centralized transit services. including a transit hub which will operate on a pulse schedule, customer service, and sales.

GRATA used to provided information at major transfer stops, however, it was discontinued because the information could not be kept current due to frequent changes. This problem could be reduced or eliminated if the en-route transit information was automatically updated by information obtained through a public transportation management system.

Personalized Public Transit

Personalized public transit provides flexibly routed transit vehicles which offer more convenient, and often more cost effective, service to customers where traditional, fixed route operations cannot be economically justified. Small. publicly or privately operated vehicles provide on-demand routing to pick up passengers who have requested service and deliver them to their destinations. Route deviation schemes, where vehicles leave a fixed route for a short distance to pick up or discharge passengers, is another possible approach. Vehicles providing this service include small buses, taxis, or other small, shared-ride vehicles. This type of service can expand transit service to lessor populated locations and neighborhoods and can potentially provide transportation at a lower cost and with greater convenience than conventional fixed route transit.

Local Applications for Personalized Public Transit. Only one of the agencies interviewed specifically indicated an interest in personalized public transit. This is presumably due to a perception that the local transit agency has other, more immediate, needs. Current applications that may be considered a part of personalized public transit include paratransit services, and route deviations to serve local schools.

Public Travel Security

The public travel security user service creates a more secure environment for transit patrons and operators by providing systems that monitor the environment in transit stations, parking lots, bus stops. and on transit vehicles. These systems generate alarms, either automatically or manually, when necessary. This improves security, and the perception and acceptance of transit. This service can be integrated with other anti-crime activities.

Local Applications for Public Travel Security. Public travel security was noted as an issue of interest by some of the agencies interviewed. The transit agency noted that some of the perceptions related to security are impacted by the fact that high school students share the buses in many cases. Many people are uncomfortable riding on the bus with the students, however. funding stipulations do not allow the students to be served exclusively.

ELECTRONIC PAYMENT

The Electronic Payment bundle includes one user service, electronic payment services, shown in Table 3-4 and discussed below.

Table 3-4 Electronic Payment User Services

Bundle	User Services
Electronic Payment Services	Electronic Payment

Electronic payment services allow travelers to pay for transportation services with electronic cards or tags. The goal is to provide travelers with a common electronic payment medium for all transportation modes and functions, including tolls, transit fares, and parking. Electronic payment services encompasses the integration of payment systems of various modes to create an intermodal user service, as well as the improvement of payment systems for separate transportation modes. Payment systems for various modes have to be perfected independently before they can be widely integrated.

Another goal is integration among systems in different states, especially with respect to toll payment. Electronic toll collection, transit fare payment, and parking payment would be linked through an inter-modal multi-use electronic system. A common fee payment structure could be used with all modes, possibly tying into roadway pricing options. Coordinated pricing strategies and incentives for HOV travel would be facilitated by such a system. Components of electronic payment services include electronic toll collection, electronic fare collection for transit, and electronic parking payment.

Local Applications for Electronic Payment. Electronic payment would currently have limited application in the Grand Rapids area. There are no toll roads in the State of Michigan, and a limited number of toll bridges. While there was once a possibility that the proposed South Belt Line would be a toll facility, this option has been eliminated from consideration at this time. This does not imply that no agencies are in favor of toll facilities, some agencies indicated that the need for adequate infrastructure warranted the implementation of tolls, taxes and/or other mechanisms for additional funding.

Another potential application of electronic payment services is for payment of transit fares. GRATA currently utilizes electronic fare boxes, however, full implementation of this user service might entail a system that is based on a debit or credit system, with weekly or monthly billing.

COMMERCIAL VEHICLE OPERATIONS

The Commercial Vehicle Operations (CVO) bundle includes six user services that are concerned primarily with freight movement and focus in two specific areas. one to improve private sector fleet management, and one to streamline regulatory functions. The user services in the Commercial Vehicle Operations bundle are shown in Table 3-5 and discussed in greater detail in the next sections.

Table 3-5 Commercial Vehicle Operations User Services

Bundle	User Services
Commercial Vehicle Operations	Commercial Vehicle Electronic Clearance Automated Roadside Safety Inspection On-Board Safety Monitoring Commercial Vehicle Administration Processes Hazardous Material Incident Response Commercial Fleet Management

Local Applications for Commercial Vehicle Operations User Services. CVO user services were considered appropriate by many of the agencies interviewed due to the volume of commercial vehicles passing through the Grand Rapids area and the large number of entities in the area that rely on CVO. In fact, Grand Rapids is the second largest in the state (Detroit is first) in terms of volume of trucks. This volume is due to the fact that much of the traffic into and out of the northern lower peninsula travels on US 31 or US-131. and due to the fact that Grand Rapids is a hub for large companies such as Steelcase, Meijer. AMWAY, and Gainey.

It should be noted that while many agencies indicated that there are a large number of commercial vehicles, many of these agencies also indicated that the large volume did not necessarily imply any problem with respect to commercial vehicles. In fact, some agencies work with the private entities to coordinate access and scheduling, and identified mobility for freight as an important consideration. Other agencies feel that more coordination is needed, specifically with respect to the location of truck termini relative to interchanges, and the scheduling of operations relative to peak periods.

Commercial Vehicle Electronic Clearance

Commercial vehicle electronic clearance would allow enforcement personnel to electronically check safety, credential, and size and weight data for transponder-equipped vehicles before they reach an inspection site, selecting only illegal or potentially unsafe vehicles for an inspection. Safe and legal carriers would be able to travel without stopping for compliance checks at weigh stations. ports-of-entry, and other inspection sites. This service will also support the North American Free Trade Agreement (NAFTA) by expediting international carriers at the Mexican and Canadian borders.

Automated Roadside Safety Inspection

Automated roadside safety inspections would use safety data provided by the electronic clearance service combined with advanced technologies to allow for more selective and rapid inspections. Through the use of sensors and diagnostics, inspectors will eventually be able to check vehicle systems and driver requirements and ultimately driver alertness and fitness for duty.

Local Applications for Commercial Vehicle Electronic Clearance and Automated Roadside Safety Inspection. These user services are addressed together because they are closely related. Commercial vehicle electronic clearance and automated roadside safety inspection are of interest to both enforcement personnel and agencies that thought it would facilitate operations for local companies. The Sixth District of the Michigan State Police already utilizes weigh-in-motion technologies, which are permanently located at I-196 and Fuller Avenue, and at the Kent and Montcalm County line. These weigh-in-motion stations are used by both MDOT and the State Police. The police use the stations as screening devices, and are very happy with the results, and are in favor of the expanded use of technology for enforcement purposes.

On-Board Safety Monitoring

On-board safety monitoring allows non-intrusive monitoring of the driver, vehicle, and cargo and notification of the driver, carrier, and possibly enforcement personnel if an unsafe situation arises. An unsafe situation might involve driver fatigue, vehicle systems, or cargo shifting. Eventually, this service will tie into the automated roadside safety inspection and electronic clearance services.

Local Applications for On-Board Safety Monitoring. On-board safety monitoring would require sophisticated technologies that have not been fully developed and tested. Because this user service relies on technologies that are not currently available, it is appropriate for implementation in the long term.

Commercial Vehicle Administrative Processes

Commercial vehicle administrative processes will allow carriers to purchase credentials and collect and report fuel and mileage tax information electronically. Through automation, this service should provide to carriers and states a significant reduction in the paperwork burden and has the potential for simplifying compliance operations.

Local Applications for Commercial Vehicle Administrative Processes. While the commercial vehicle administrative processes user service is of interest to agencies that think it would facilitate operations for local companies, it is more appropriate for implementation by state regulatory agencies, rather than for implementation at a local level.

Hazardous Materials Incident Response

Hazardous materials incident response would provide emergency response personnel at the scene of a hazardous materials in&dent immediate information on the types and quantities of hazardous materials present in order to facilitate a quick and appropriate response.

The National Academy of Sciences determined that it is not cost effective to track all hazardous material shipments. For certain types and amounts of hazardous materials it may only be important to locate these trucks when they are involved in a serious accident/incident and then provide specific cargo information to the appropriate emergency responders.

Local Applications for Hazardous Material Incident Response. Hazardous materials incident response is of interest to many agencies. This is not unexpected, due to the fact that it complements the incident management user service. Hazardous materials incident response is provided by MDOT. the Kent County Road Commission and the State Police. In responding to hazardous material incidents. these agencies set up the traffic diversions and assess what agency should be contacted to respond to the spill. The large volume of commercial vehicle traffic through Grand Rapids may warrant some consideration to hazardous materials incident response.

Freight Mobility

Freight mobility provides links between drivers, dispatchers, and inter-modal transportation providers, enabling carriers to take advantage of real-time traffic information, as well as vehicle and load location information, to increase productivity.

Local Applications for Freight Mobility. While freight mobility was identified as appropriate for some of the entities in the area that have a significant number of trucks, this user service is more appropriate for implementation by private, rather than public entities, due to the fact that the benefits will accrue primarily to the private entity. Furthermore, most of the larger fleets in the area already have dispatcher to vehicle communications capabilities.

EMERGENCY MANAGEMENT

The Emergency Management bundle includes two user services that relate directly to the detection, notification, and response to emergency and non-emergency incidents which take place on or adjacent to the roadway. The focus is the improvement of the ability of roadside service providers, as well as the ability of police, fire, and rescue operations to respond appropriately, thereby saving lives and reducing property damage. The user services in the Emergency Management bundle are shown in Table 3-6 and discussed in greater detail in the following sections.

Local Applications of Emergency Management User Services. In general, emergency management user services are of interest because they would complement incident management activities, and anything that contributes to incident management is considered important.

Table 3-6 Emergency Management User Services

Bundle	User Services
Emergency Management	Emergency Notification and Personal Security Emergency Vehicle Management

Emergency Notification and Personal Security

Emergency notification and personal security focuses on decreasing the time it takes for responding agencies to be notified of emergency and non-emergency incidents, and providing an accurate estimate of the location of the vehicle in need of assistance. This service includes both driver and personal security, in instances where manual notification of incidents is possible, and automated collision notification, in cases where incident severity precludes manual notification of incidents.

Local Applications for Emergency Notification and Personal Security. Emergency dispatch is currently provided via a 911 system. There is currently a central dispatch for Ottawa County. and there are plans to provide a central dispatch for Kent County. These central dispatch systems allow the closest available responder to be dispatched. The central dispatch for Kent County is in the planning stages and it's location has not been determined at the time of printing this report. A new Regional Dispatch building will house the Sixth District headquarters of the State Police. It has been suggested that this would be an appropriate location for the future traffic management center (TMC), because locating the TMC center in the same building as the dispatch would enhance coordination and communication between the emergency response and traffic operations activities.

Emergency Vehicle Management

Emergency vehicle management focuses on decreasing the time it takes for agencies to respond once the incident is reported to the operator or dispatcher. This includes three subservices, emergency vehicle fleet management, route guidance, and signal priority. Emergency vehicle fleet management provides information regarding emergency vehicle location, and automated support to dispatchers to help determine which vehicle can most quickly reach the incident site. Route guidance will assist in the determination of the quickest route to the incident scene, and from the scene to the hospital, if needed. Signal priority would provide the capability to pre-empt traffic signals on emergency vehicle's route, and the capability to warn drivers that an emergency vehicle is approaching.

Local Applications for Emergency Vehicle Management. Emergency vehicle management will be facilitated by implementation of a central dispatch for Kent County. although this central dispatch system would not preclude the City of Grand Rapids from having their own dispatch. Emergency vehicle fleet management will also be enhanced by the implementation of the new 800 MHz digital communication system that the state police will soon procure. This system, which will also have a global positioning system, will be available to MDOT and the City of Grand Rapids for dispatching their vehicles, and is expected to have data transmission capabilities, which will further enhance management capabilities.

With respect to signal priority, some agencies within the metropolitan area have already implemented signal pre-emption for emergency responders, for example, an Opticom system is in place on all major fire routes in Wyoming. This system, which is utilized by both fire trucks and emergency medical responders, has proven very satisfactory since its installation approximately three years ago. Overall in the Grand Rapids area nearly 100 intersections are equipped with the Opticom system.

ADVANCED VEHICLE SAFETY SYSTEMS

The Advanced Vehicle Safety Systems bundle includes seven user services that are related primarily to the safety goals of ITS, by diminishing the number of severity of crashes. The user services in the Advanced Vehicle Safety Systems bundle are shown in Table 3-7. A brief definition of each user service is provided following a general discussion regarding the local applicability of this bundle of user services.

Table 3-7 Advanced Vehicle Safety Systems User Services

Bundle	User Services
Advanced Vehicle Safety Systems	Longitudinal Collision Avoidance
	Lateral Collision Avoidance
	Intersection Collision Avoidance
	Vision Enhancement for Crash Avoidance
	Safety Readiness
	Pre-Crash Restraint Deployment
	Automated Highway Systems

Local Applications for Advanced Vehicle Safety Systems User Services. The technologies necessary for the user services in the Advanced Vehicle Safety Systems bundle are currently being researched and developed at the national level by automobile manufacturers and other interested entities. Most of these user services are expected to be available in automobiles. and thus implementation will be a private sector, rather than public sector, activity. The exception to this may be the implementation of the automated highway systems user service, which public entities would be expected to play a role in. However, the technologies needed for this user services have not yet been developed, and implementation of this user service is not expected in the planning horizon considered in this study.

Longitudinal Collision Avoidance

Longitudinal Collision Avoidance systems address vehicle collisions in which one or two vehicles are moving in essentially the same path prior to the collision, or in which one of the vehicles is stationary (for example, a rear end collision).

Lateral Collision Avoidance

Lateral Collision Avoidance systems address one or two vehicle collisions that arise when a vehicle leaves its own lane of travel while moving forward, for example, for the merge or lane change maneuver.

Intersection Collision Avoidance

Intersection Collision Avoidance systems address collisions that arise when vehicles improperly violate the right of way of other vehicles, or when right of way at an intersection is not clear (for example, right angle accidents). This service will provide warnings of imminent collisions with crossing traffic, as well as warnings of control devices at upcoming intersections.

Vision Enhancement for Collision Avoidance

Vision Enhancement for Collision Avoidance will address collisions in which limited visibility is a factor. The system will enhance visually acquired information when driving visibility is low, such as at night or in fog. It will not, however, compensate for blind spots or other visual obstructions.

Safety Readiness

Safety Readiness addresses collisions caused by fatigued or impaired drivers, malfunctioning vehicle components, or degraded infrastructure conditions. Safety Readiness includes three subsystems: driver condition warning and control override, vehicle condition warning, and in-vehicle infrastructure condition warning.

Pre-Collision Restraint Deployment

Pre-Collision Restraint Deployment provides a means to anticipate an imminent collision and activate safety systems (such as side impact airbags) prior to impact. The equipment is contained entirely in the vehicle.

Automated Highway Systems

The Automated Highway Systems user service focuses on improving the safety, efficiency, and comfort of the roadway system by providing fully automated control of equipped vehicles on equipped highways, as well as partial vehicle control (extension of the collision avoidance systems).

AGENCY RANKINGS OF ITS USER SERVICES

All of the representatives of the agencies interviewed (shown in Appendix A, Table A-l) were requested to rank the twenty-two ITS user services in terms of priority (all user services were ranked except those in the Advanced Vehicle Safety Systems bundle). User services were ranked high to none. Fourteen priority rankings were returned and the results are shown in Table 3-8. All of the agency rankings and comments are shown in Appendix B, Table B-l. Based on the agency rankings, the user services were divided into four groups indicating relative priority.

Highest Priority

The highest priority group includes the ITS user services in the first four rows of Table 3-8: Traffic Control, Incident Management, Hazardous Material Incident Response, and Emergency Vehicle Management. These user services address both recurring and incident related congestion. Note that these user services all contribute to the efficient identification and removal of incidents and to the reduction of the impact of incidents. These user services address both typical conditions such as recurring congestion (Traffic Control). as well as conditions related to incidents (Traffic Control, Incident Management, Hazardous Material Incident Response, and Emergency Vehicle Management). The fact that all user services of the highest priority relate to incidents reflects the fact that much of the delay in the Grand Rapids area is incident related.

Medium-High Priority

The medium-high priority group includes six ITS user services: Emergency Notification and Personal Security, En-Route Driver Information, Pre-Trip Travel Information, Public Travel Security, Demand Management and Operations, and Route Guidance. These user services relate primarily to communications with motorists (En-Route Driver Information. Pre-Trip Travel Information, Route Guidance), as well as incident response (Emergency Notification and Personal Security, En-Route Driver Information, Pre-Trip Travel Information, Route Guidance), and safety (Emergency Notification and Personal Security, Public Travel Security). The Demand Management and Operations user service is not targeted to benefit the primary roadway user, the single occupant commuter, as much as it is to the high occupancy vehicles. Note that, in many cases, there is overlap between the user services and to the functions that they contribute. For example, the user services related to communications (En-Route Driver Information, Pre-Trip Travel Information, Route Guidance) not only inform the public about roadway conditions and alternate routes, but also facilitate the incident management user service.

Medium Priority

The medium priority group includes four ITS user services: Public Transportation Management, On-Board Safety Monitoring, Traveler Services Information, and Ride Matching and Reservation. Although some of these user services relate to safety (On-Board Safety Monitoring) and communication (Traveler Services Information), these user services are generally more specific, and serve a smaller audience. For example, Traveler Services Information, while it may be used to some extent by all motorists, would probably address the needs of visitors and tourists to greater extent than it would the needs of local transportation users.

Low Priority

The low priority group includes eight ITS user services: Commercial Vehicle Electronic Clearance, En-Route Transit Information, Personalized Public Transit, Automated Roadside Safety Inspection, Freight Mobility. Commercial Vehicle Administrative Processes, Electronic Payment Services, and Emissions Testing and Mitigation. These are user services that would primarily benefit a smaller audience, and address issues that are not currently of the highest priority in the Grand Rapids area. Some of these user services are primarily targeted to commercial vehicle operators (Commercial Vehicle Electronic Clearance, Automated Roadside Safety Inspection, Freight Mobility, Commercial Vehicle Administrative Processes), others are primarily targeted to transit (En-Route Transit Information, Personalized Public Transit), while others address issues that have not been identified as critical problems in the metropolitan area (Electronic Payment Services, and Emissions Testing and Mitigation).

Table 3-8 Overall Priority Rankings of ITS User Services by Local Agencies

User Service	Rank	Priority
Traffic Control	1	Highest
Incident Management	2	
Hazardous Material Incident Response	3	
Emergency Vehicle Management	4	
Emergency Notification as Personal Security	5	Medium-High
En-Route Driver Information	6	
Pre-Trip Travel Information	7	
Public Travel Security	8	
Demand Management and Operations	9	
Route Guidance	10	
Public Transportation Management	11	Medium
On-Board Safety Monitoring	12	
Traveler Services Information	13	
Ride Matching and Reservation	14	
Commercial Vehicle Electronic Clearance	15	Low
En-Route Transit Information	16	
Personalized Public Transit	17	
Automated Roadside Safety Inspection	18	
Freight Mobility	19	
Commercial Vehicle Administrative Processes	20	
Electronic Payment Services	21	
Emissions Testing and Mitigation	22	

PERFORMANCE CRITERIA FOR ITS USER SERVICES

Fifteen performance criteria have been developed to evaluate the impacts of the implementation of ITS user services. These performance criteria, shown in Table 3-9, address a variety of transportation issues:

- **Capacity,** including recurring congestion (#l) and transportation efficiency (#2);
- **Incidents,** including incident related congestion (#3), and incident management activities (#4).
- **Safety,** including the safety of emergency personnel at an incident site (#5), and public safety, both in private vehicles and on public transit (#6).
- **Alternatives to the Single Occupant Vehicle** (SOV), including transit service (#7), ride-sharing (#8), and the provision of the incentives for the use of high occupancy vehicles (HOVs) (#9).
- **Environmental,** including compliance with mandates for clean air (#l0).
- **Institutional,** including activities within an agency (#l1), and the coordination of the activities of various agencies (# 12).
- **User Related,** including user convenience (#13), communications with users (#14), and impacts on user behavior (#15).

Because multiple performance criteria often address various aspects of a single issue, the inclusion of one performance criteria often leads to the inclusion of other performance criteria. for example:

- A user service that enhances/facilitates incident management (#2) would often be expected to reduce incident related congestion (#3).
- A user service that enhances transit service or ride-sharing (#7 and #8), may be expected to increase average vehicle occupancy levels (#5), which would in turn increase transportation efficiency (#2) and facilitate compliance with clean air mandates (#l0).
- A user service that reduces recurring congestion (#l) would be expected to increase transportation efficiency (#2).

Note that. in general, the performance criteria may be used to evaluate impacts either for specific projects. or on an area wide basis. For example, attainment of the first performance criteria, Reduce Recurring Congestion, can be evaluated by examining either a specific facility or facility segment, or by examining all major facilities in the area to determine an average or aggregate level of recurring congestion on an area wide basis.

Measures Of Effectiveness

The performance criteria are generally quantified by measures of effectiveness (MOE’s). which may be used to compare actual performance to objectives and criteria. Measures of effectiveness for each of the 15 performance criteria are shown in Table 3-9.

Multiple measures of effectiveness are provided for each performance criteria. Both qualitative and quantitative measures are included for many of the performance criteria (all of the MOE's identified for each performance criteria are shown in Appendix C, Table C-l). Qualitative measures are especially important for the evaluation of issues such as agency coordination, user convenience, and other measures that are critical to the success of a project but are difficult to quantify.

Note that the performance criteria do not address all of the issues that would need to be evaluated upon implementation of a user service. For example, the maintenance, reliability and accuracy of a system would be critical to its success, although these issues are not directly addressed by the performance criteria. Furthermore. impacts of maintenance activities (frequency of maintenance, disruption of traffic due to maintenance, etc.) and impacts of equipment reliability and accuracy (frequency of "false alarms" for incident detection systems, disruption of traffic due to such false alarms in terms of deployment of emergency response vehicles, inaccurate reports to motorists, etc.) must be considered, although they are not addressed by these performance criteria.

The following text discusses the performance criteria for the user services identified as highest and medium-highest priority, based on the agency rankings. Performance criteria for all user services are shown in Appendix C.

Table 3-9 Performance Criteria and Sample Measures of Effectiveness

Transportation Issue	Performance Criteria	Sample Measure of Effectiveness
Capacity	Reduce Recurring Congestion	Vehicle hours of delay in peak hour
	Increase Transportation Efficiency	Person miles traveled per lane mile
Incidents	Reduce Incident Related Congestion	Vehicle hours of delay due to incidents
	Enhance/Facilitate incident Management	Capability to detect incident and identify incident location
Safety	Improve Safety of Emergency Personnel at Incident Site	Volume and speed of traffic adjacent to incident site
	Increase Safety	Accident rate
Alternatives to the Single Occupant Vehicle	Enhance Transit Service	Schedule adherence, on-time performance
	Enhance Ride-sharing	Number of employer and employee participants in ride-sharing program
	Increase Average Vehicle Occupancy / Provide Incentives for HOV Use	Number and percentage of SOV, carpool, van pool, and bus trips
Environmental	Facilitate Compliance with Clean Air Mandates	Capability to monitor vehicle emissions
Institutional	Enhance Agency Activities	Reduction in personnel hours required to perform necessary functions
	Integrate Transportation Services	Number of coordinating agencies
User Related	Improve User Convenience	Qualitative assessment of convenience
	Enhance Communications with Public	Number and percentage of public with access to information
	Affect Commuter Behavior	Number and percentage of commuters who change travel route, time of travel, or travel mode

Performance Criteria For High Priority User Services

Performance criteria that may be appropriate for the evaluation of each of the user services identified as highest priority in *Agency Rankings* of *ITS* User *Services* are shown in Table 3-10 and briefly discussed in the following text.

Table 3-10 Performance Criteria for High Priority User Services

Performance Criteria	Performance Criteria for Highest Priority User Services			
	Traffic Control	Incident Management	Hazardous Material Incident Response	Emergency Vehicle Management
1. Reduce Recurring Congestion	X			
2. Increase Transportation Efficiency	X	X		
3. Reduce Incident Related Congestion	X	X		X
4. Enhance/Facilitate Incident Management	X	X		X
5. Improve Safety of Emergency Personnel at Incident Site	X	X	X	
6. Increase Safety	X	X	X	
7. Enhance Transit Service				
8. Enhance Ride-sharing				
9. Increase Average Vehicle Occupancy / Provide Incentives for HOV Use				
10. Facilitate Compliance with Clean Air Mandates	X			
11. Enhance Agency Activities	X	X	X	X
12. Integrate Transportation Services		X		
13. Improve User Convenience				
14. Enhance Communications with Public				
15. Affect Commuter Behavior				

Performance Criteria for Traffic Control and Incident Management

The performance criteria for both Traffic Control and Incident Management reflect the fact that these user services would be expected to increase the safety and efficiency of the transportation system during and after incidents. Thus performance measures include those related to incidents: Reduce Incident Related Congestion (#3), Enhance/Facilitate Incident Management (#4), Improve Safety of Emergency Personnel at Incident Site (#5): and those reflecting the resulting increase in safety and efficiency: Increase Safety (# 6) and Increase Transportation Efficiency (#2). Enhance Agency Activities (#ll) is also identified as a performance measure since implementation of these user services would be expected to provide agencies with data and information not currently available. Traffic Control would also be expected to provide benefits during typical operating conditions, and thus it would Reduce Recurring Congestion (#l) and Facilitate Compliance with Clean Air Mandates (#l0). Incident Management would be expected to Integrate Transportation Services (#12), because it would enhance coordination between agencies involved in incident management activities.

Performance Criteria for Hazardous Material Incident Response

Performance criteria for Hazardous Material Incident Response reflect the fact that the provision of immediate information about hazardous material would be expected to Improve Safety of Emergency Personnel at the Incident Site (#5) as well as Increase Safety (#6) of motorists. The provision of hazardous material information would also Enhance/Facilitate Incident Management (#4) and Enhance Agency Activities (#ll) for the agencies responsible for identifying and cleaning hazardous materials.

Performance Criteria for Emergency Vehicle Management

Emergency Vehicle Management performance criteria reflect the fact that this user service would be expected to Reduce Incident Related Congestion (#3), Enhance/Facilitate Incident Management (#4) and Enhance Agency Activities (#11) since it would facilitate incident detection and emergency response to incidents.

Performance Criteria For Medium-High Priority User Services

Performance criteria that may be appropriate for the evaluation of each of the user services identified as medium-high priority in *Agency Rankings of ITS User Services* are shown in Table 3-11 and briefly discussed in the following text.

Performance Criteria for Emergency Notification and Personal Security

Performance criteria for Emergency Notification and Personal Security show that this user service would be expected to Reduce Incident Related Congestion (#3), Enhance/Facilitate Incident Management (#4), since it would facilitate incident detection and emergency response to incidents, and Increase Safety (#6) for the public.

Reduce Recurring Congestion (#l) and Enhance Agency Activities (#l1) are also identified as performance criteria for Route Guidance. Enhance Agency Activities (#l1) is identified as a performance criteria because the provision of route guidance information via advanced technologies would allow enforcement personnel to concentrate on traffic control during incidents. and relieve them of the duty of providing directions. Reduce Recurring Congestion (#1) is specified as a performance criteria based on the assumption that some recurring congestion is due to the fact that drivers do not always select their route based on a complete analysis of all of the available routes. A Route Guidance user service that provides the "minimum time route" would reduce the impacts of recurring congestion by diverting motorists from routes that are typically congested to less congested routes, assuming that less congested routes exist. While many of the benefits of Route Guidance on a system-wide basis are related to incidents, it is important to note that the Route Guidance user service also provides valuable information to tourists and motorists unfamiliar with the local roadway network. This benefit would be quantified under the performance criteria Improve User Convenience (#13).

Table 3-11 Performance Criteria for Medium-High Priority User Services

Performance Criteria	Overall Medium-High Priority User Services				
	Emergency Notification and Personal Safety	En-Route Driver Information	Pre-Trip Travel Security	Public Travel Security	Demand Management and Operations
1 Reduce Recurring Congestion					X
2. Increase Transportation Efficiency		X	X	X	X
3. Reduce Incident Related Congestion	X	X	X		
4. Enhance/Facilitate Incident Management	X	X			
5. Improve Safety of Emergency Personnel at Incident Site		X	X		
6. Increase Safety	X			X	
7. Enhance Transit Service			x	X	X
8. Enhance Ride-sharing			X		X
9. Increase Average Vehicle Occupancy / Provide Incentives for HOV Use			X	X	X
IO. Facilitate Compliance with Clean Air Mandates			X	X	X
I I. Enhance Agency Activities					
12. Integrate Transportation Services			X		
13. Improve User Convenience		X	X		
14. Enhance Communications with Public		X	X		
15. Affect Commuter Behavior		X	X	X	X

Performance Criteria for Pre-Trip Travel Information

Many of the benefits of Pre-Trip Travel Information are expected due to the fact that information regarding transportation alternatives is provided before a mode choice has been made, thus the performance criteria focus on changes in commuter behavior that result from the provision of this information, and the impacts of these changes.

Pre-Trip Travel Information performance criteria related to a change in mode include Enhance ridesharing (#8), which would be expected to Affect Commuter Behavior (#15) and Increase Average Vehicle Occupancy/Provide Incentives for HOV use (#9). An increase in vehicle occupancy would be expected to Increase Transportation Efficiency (#2) and Facilitate Compliance with Clean Air Mandates (#l0). While performance criteria such as those related to increases in HOV modes are included for this and other user services, it is important to note that such mode changes would only be expected if there were some incentives for HOV use (employer incentives, exclusive HOV lanes, pricing incentives, etc.).

In addition to impacts related to changes in mode choice, Pre-Trip Travel Information would be expected to have impacts due to incidents or other unusual conditions. Because some motorists may be expected to delay or re-route their trip when they find out about an incident, Pre-Trip Travel Information would be expected to Reduce Incident related Congestion (#3), and thus Improve Safety of Emergency Personnel at Incident Site (#5) by reducing the volume of traffic adjacent to the incident location. Pre-Trip Travel Information would also Enhance Transit Service (X7), Improve User Convenience (#13) and Enhance Communications with Public (#14), as well as Integrate Transportation Services (#12) by providing information about a variety of transportation alternatives.

Performance Criteria for Public Travel Security

Public Travel Security performance criteria focus on the increased security of transit, and the extent to which this enhances transit service and increases vehicle occupancies. The performance criteria include: Increase Transportation Efficiency (#2). Increase Safety (#6), Enhance Transit Service (#7), Increase Average Vehicle Occupancy/Provide Incentives for HOV Use (#9), Facilitate Compliance with Clean Air Mandates (#l0), and Affect Commuter Behavior (#15).

Performance Criteria for Demand Management and Operations

The performance criteria for Travel Demand Management and Operations focus on the increase in efficiency in the use of the highway system and its impacts on public transit and ride-sharing. The performance criteria include: Reduce Recurring Congestion (# 1). Increase Transportation Efficiency (#2), Enhance Transit Service (#7), Enhance Ride-Sharing (#8), Increase Average Vehicle Occupancy/Provide Incentives for HOV Use (#9). Facilitate Compliance with Clean Air Mandates (#l0), and Affect Commuter Behavior (#15). An increase in vehicle occupancy and the increase in efficiency would be expected to Reduce Recurring Congestion (#1).

ITS CORE INFRASTRUCTURE

The ITS "core infrastructure" consists of seven elements that contribute to the deployment of ITS traffic management and traveler information services in a metropolitan area, and will establish a foundation for the deployment of future ITS user services[5]. The core infrastructure focuses on metropolitan Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS), and does not address the user services in the Commercial Vehicle Operations bundle and the Advanced Vehicle Safety Systems bundle. The seven elements included in the core infrastructure are as follows:

1. Regional Multimodal Traveler Information Center (RMTIC): The RMTIC compiles and maintains current roadway and transit information, and is the link between the general public and the transportation system managers.

2. Traffic Control Systems: Signal control systems increase transportation efficiency by adjusting green times to maximize vehicle and pedestrian capacity and minimize delay.

3. Freeway Management Systems: Freeway management systems monitor freeway traffic conditions, identify recurring and non-recurring congestion, and allow implementation of control and management strategies such as route diversion and traveler information via Variable Message Signs (VMS) and highway advisory radio (HAR).

4. Transit Management Systems: Transit Management systems include fleet management systems and advanced computer and communications equipment on vehicles and in dispatching centers. These systems improve security and increase the efficiency of operations and maintenance.

5. Incident Management Program: Incident management programs facilitate the rapid identification and removal of incidents on freeways and arterials, reducing delay and driver frustration.

6. Electronic Fare Payment: Electronic fare payment for transit eliminates the need for transit patrons to provide exact change, and facilitate the coordination of fares among multiple transit providers.

7. Electronic Toll Collection: Electronic toll collection allows drivers to pay tolls without stopping, decreasing delays and enhancing transportation efficiency.

The identification of core infrastructure elements is intended to guide near-term deployment decisions, and at the same time to facilitate opportunities in the future for the implementation of ITS user services. Implementation of the core infrastructure is expected to be led by the public sector, although private sector participation is encouraged. The implementation of core elements in a number of metropolitan areas is expected to provide a foundation which will allow the private sector to develop products and industries for future ITS user services.

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5 Discussion on ITS core infrastructure is based on Draft *Core ITS Infrastructure Elements for Metropolitan Area, ATMS/ATIS Deployment* provided at the *Early Deployment Planning Workshop* on March 14, 1995 at The Grand Hyatt in Washington, D.C.. sponsored by FHWA.

The following sections discuss the principles which guided the definition of the core infrastructure elements, and key considerations for implementation of the elements of the core infrastructure. These principles and key considerations provide insight into justification for the elements in the core infrastructure, as well as guidance regarding deployment of projects that contribute to the core infrastructure.

Core Infrastructure Principles

A number of principles were considered in the definition of the core infrastructure elements, these include:

- Deployment of elements will enable implementation of ATMS/ATIS user services, and facilitate implementation of other ITS user services.
- Each element can be deployed independently, although concurrent implementation would provide economies of scale through either increased overall benefits or decreased marginal costs.
- Elements can be deployed in the near term using state-of-the-art concepts and technologies, and would often be eligible for Federal funding.
- Elements can be deployed using varying technologies, from low-tech to high-tech.
- Elements are appropriate for implementation in a variety of environments (considering institutional arrangements, geographic/spatial development patterns. etc.) and elements will evolve to provide increased benefits and/or lower costs.
- Private sector participation in the development of core elements and the implementation of ATMS/ATIS user services is encouraged, particularly with respect to the collection and provision of traveler information.

Key Considerations for Deployment

Key considerations for the deployment of the core infrastructure elements include the fact that muitipie elements utilize common hardware and software components, and face similar institutional issues prior to and upon implementation. Many of the key considerations address equipment, communications, institutional, and management issues, as noted below:

- Capability to distribute multimodal traveler information to the general public.
- Capability for surveillance and detection, resulting in current, complete and accurate traffic and transit information.
- Communications systems linking field equipment with central systems for database management.
- Communications among jurisdictions, agencies and organizations, in both the public and private sectors, without any implied change in control and/or responsibility (for example, information sharing and coordination with emergency and hazardous material responders).

- Proactive management of resources. both roadway and transit, to achieve the transportation objectives of the metropolitan area.
- Continuing support for system operations and maintenance needs, including personnel requirements, such as training.

SHORT, MEDIUM, AND LONG TERM ITS USER SERVICES

A time frame for implementation has been identified for each of the ITS user services, and is shown in Table 3-12. The time frame associated with each user service was based on a number of things, including input from local agencies (discussed in *Agency Perceptions of the Local Applicability* of *ITS User Services).* agency rankings of priority (discussed in *Agency Rankings of ITS User Services),* the state of technology that is needed to implement various aspects of the user service, and whether or not the user service contributes to the core infrastructure. In general, the specified implementation time frame corresponds to the priority indicated by the local agencies unless there are other limiting factors, such as available technology. User services are identified for implementation in the short term (within five years), medium term (within ten years), or long term (over ten years).

It is important to note that a single user service could encompass any number of specific projects, some of which require minimal technology and thus could be implemented in the short term, and others which require very sophisticated technology that is currently in the research, or even theoretical, stage. For example, consider the Emergency Notification and Personal Security user service. A low-tech project geared toward the objectives of this user service would be to install milepost markers on the freeway, as well as identify the roadway on bridge overpasses, so that people calling in to report an incident could more accurately communicate their exact location. On the other hand, a high-tech project geared toward the objectives of this user service would be automatic collision notification, which may be an in-vehicle device that would be activated upon impact (like an airbag) and would automatically send out a distress signal that would be received at the traffic control center or by emergency dispatch.

The issue of technologies brings up the point that any plan that incorporates “advanced technologies” as a component must necessarily be dynamic, changing to reflect and utilize new technologies and applications. Many technologies are rapidly evolving, and these evolutions cannot always be anticipated. This user service plan must be modified to reflect not only changing circumstances, but also changing technologies.

It is also important to re-iterate that there is often overlap between the various user services. A single project might fulfill the objectives of two or more of the user services. For example, a changeable message sign could be used to provide En-Route Driver Information, moreover, the information provided could be regarding a detour or alternate route around an incident, thus providing Route Guidance, and enhancing Incident Management.

The many factors that have been discussed above that are related to the ITS user services, priority, and implementation time frame are not intended to negate the value of the identification of priority and implementation time frame for each user service, but are rather intended to emphasize the limitations of the identification of priority and implementation time frame. In summary, the priority and implementation time frame noted for each user service should perhaps be considered a general, rather than an absolute, guideline. Actual implementation time frame would also be affected not only by priority and the availability of proven technology, but also by opportunity and available funding. Road widening projects and other activities may present the opportunity to implement advanced technologies at a much lower cost, making implementation of certain user services appropriate, even though they may not be otherwise.

Existing or Planned ITS User Services

Six user services are identified as being either existing or planned, as shown in Table 3-12. Additional details about the projects that have been implemented for each of these user services were provided *in Chapter 2: Current and Planned ITS Applications in the Grand Rapids Area.* A priority and implementation time frame have also been identified for each of these user services, this is intended to address other projects that would also address the objectives of the user service.

Table 3-12 Priority and Implementation Time Frames for ITS User Services

User Service	Implementation Time Frame			
	Existing or Planned	Short	Medium	Long
1. Traffic Control	X	High		
2. Incident Management	X	High		
3. Hazardous Material Incident Response		High		
4. Emergency Vehicle Management		High		
5. Emergency Notification and Personal Security		Medium High		
6. En-Route Driver Information	X	Medium High		
7. Pre-Trip Travel Information	X	Medium High		
8. Public Travel Security			Medium High	
9. Demand Management & Operations			Medium High	
10. Route Guidance			Medium High	
11. Public Transportation Management			Medium	
12. Commercial Vehicle Electronic Clearance	X		Low	
13. Automated Roadside Safety Inspection	X		Low	
14. On-board Safety Monitoring				Medium
15. Traveler Services Information				Medium
16. Ridesharing and Reservation				Medium
17. En-Route Transit Information				Low
18. Personalized Public Transit				Low
19. Freight Mobility				Low
20. Commercial Vehicle Administrative Processing				Low
21. Electronic Payment Services				Low
22. Emissions Testing and Mitigation				Low

User Services for Implementation in the Short Term

Seven user services are identified as appropriate for implementation in the short term. These user services included all of the user services that were identified as highest priority in the agency rankings. These user services address both recurring congestion (Traffic Control) and incidents (Traffic Control, Incident Management, Hazardous Material Incident Response, Emergency Vehicle Management, Emergency Notification and Personal Security, En-Route Driver Information). These user services also enhance communications (En-Route Driver Information, Emergency Notification and Personal Security, Pre-Trip Travel Information). The Emergency Notification and Personal Security and En-Route Driver Information user services are considered medium-high priority while Traffic Control, Incident Management, Hazardous Material Incident Response and Emergency Vehicle Management are considered high priority, reflecting the input of all the agencies surveyed.

Traffic Control and Incident Management user services provide significant contributions to the core infrastructure. Furthermore, both the Emergency Vehicle Management and Emergency Notification and Personal Security user services would play an important role in an incident management program.

User Services for Implementation in the Medium Term

Six user services are identified as appropriate for implementation in the medium term. These user services mainly address agency interests in communicating with motorists (Route Guidance). The user services also include transit service interests (Public Travel Security, Public Transportation Management, Demand Management and Operations) and commercial vehicle concerns (Commercial Vehicle Electronic Clearance and Automated Roadside Safety Inspection). The commercial vehicle user services are included here because of the existing "weigh-in-motion" stations in the area.

User Services for Implementation in the Long Term

The remaining nine user services are identified as appropriate for implementation in the long term. These user services address a variety of issues, including issues primarily targeted to commercial vehicle operators (Commercial Vehicle Administrative Processes, Freight Mobility, On-Board Safety Monitoring), and ridesharing (Ride-matching and Reservation). The user services also address issues that have not been identified as critical problems in the metropolitan area (Electronic Payment Services, Emissions Testing and Mitigation) and issues that cannot be addressed at this time due to financial constraints (Traveler Services Information, Personalized Public Transit, En-Route Transit Information).

Chapter 4
SYSTEM ARCHITECTURE

NATIONAL ARCHITECTURE OVERVIEW

The emergence of an ITS National Architecture now provides a definitive road map for geographically diverse areas to implement ITS designs and deployment strategies in a consistent manner. While the National Architecture is not totally defined, it is sufficiently developed to provide general direction and guidance in formulating solutions to transportation issues and the provision of core user services. The Physical Architecture volume (FHWA, 1995) forms the basis for the architecture definitions presented herein.

There are four basic elements of the architecture:

- Users: The class of people who interface with architecture implementation as travelers or operators. The capabilities and services of ITS would be utilized for improved travel, enhanced service, streamlined operations, and increased profits.
- External Systems: The computer systems outside of ITS that interface with the architecture.
- System Environment: The physical world of roadway, air, obstacles, etc.
- Internal Subsystems: The key elements of the Architecture that interact to provide ITS services and functionality.

These four basic elements provide a very top level architecture, as shown in Figure 4-1, for the eighteen subsystems that are defined in the National Architecture. To show completeness of the system, Figure 4-2 presents a comprehensive view of the information flows for all subsystems. These elements and subsystems will be simplified for the development of appropriate subsystems necessary and sufficient to meet the user services and priorities established in the previous sections. It should be emphasized, however, that adhering to this model should provide for the reintroduction of additional detail sufficient to accommodate growth as conditions change and it becomes necessary to implement new/evolving user requirements within the project area.

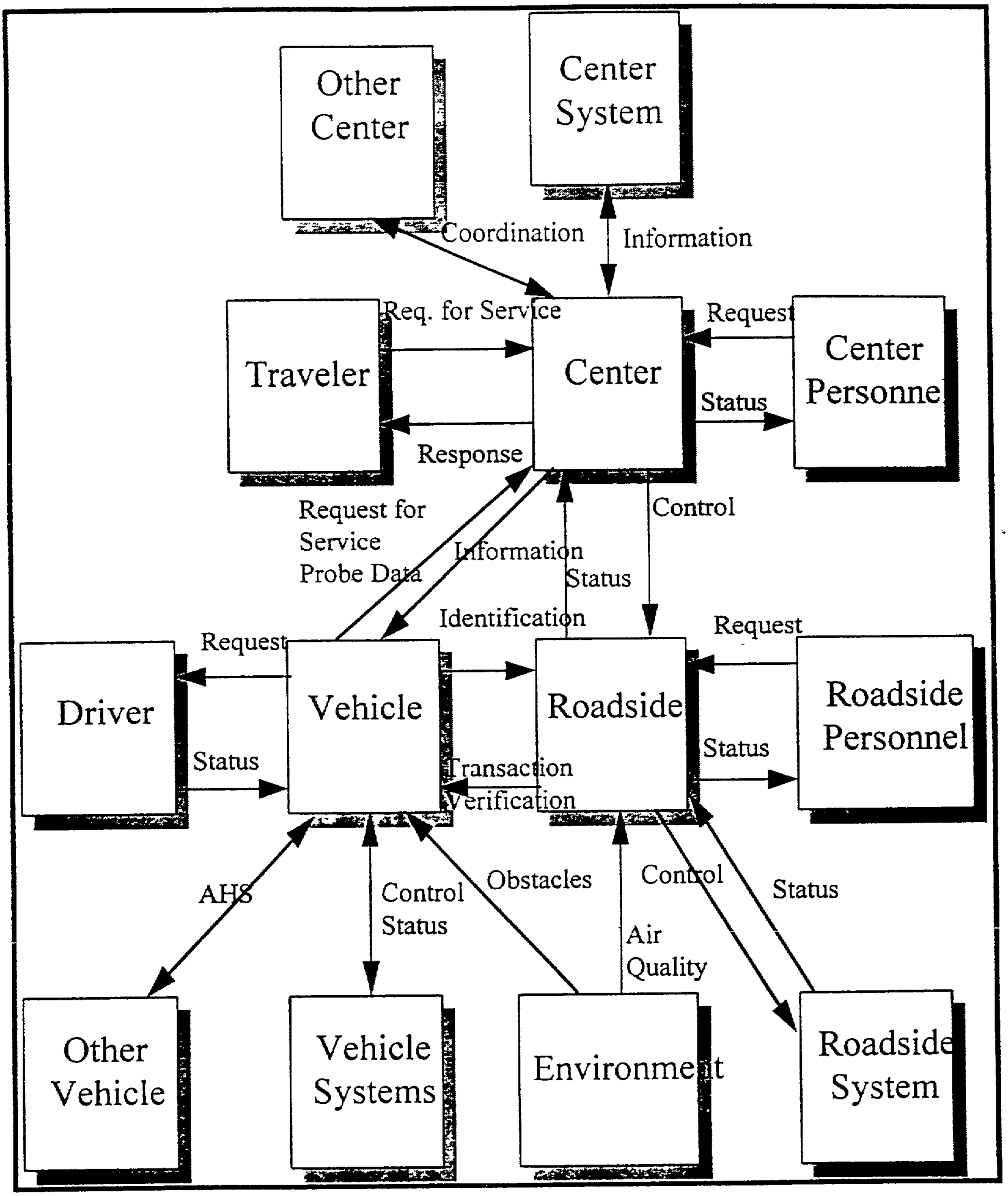
GRAND RAPIDS ARCHITECTURE

ITS Subsystem Definitions

ITS subsystems are categorized into four functional perspectives known as “classes”. These include:

- “Centers”, which collect, process, and store information
- “Roadsides”, which encompasses elements deployed along the “roadway” regardless of the type of "road" (e.g. rail, air, sea)
- “Vehicles”, which travel the “roadways”
- “Travelers Remote Access”, which represents ITS users with transportation needs.

Figure 4-1 Very Top Level Architecture Flow Diagram



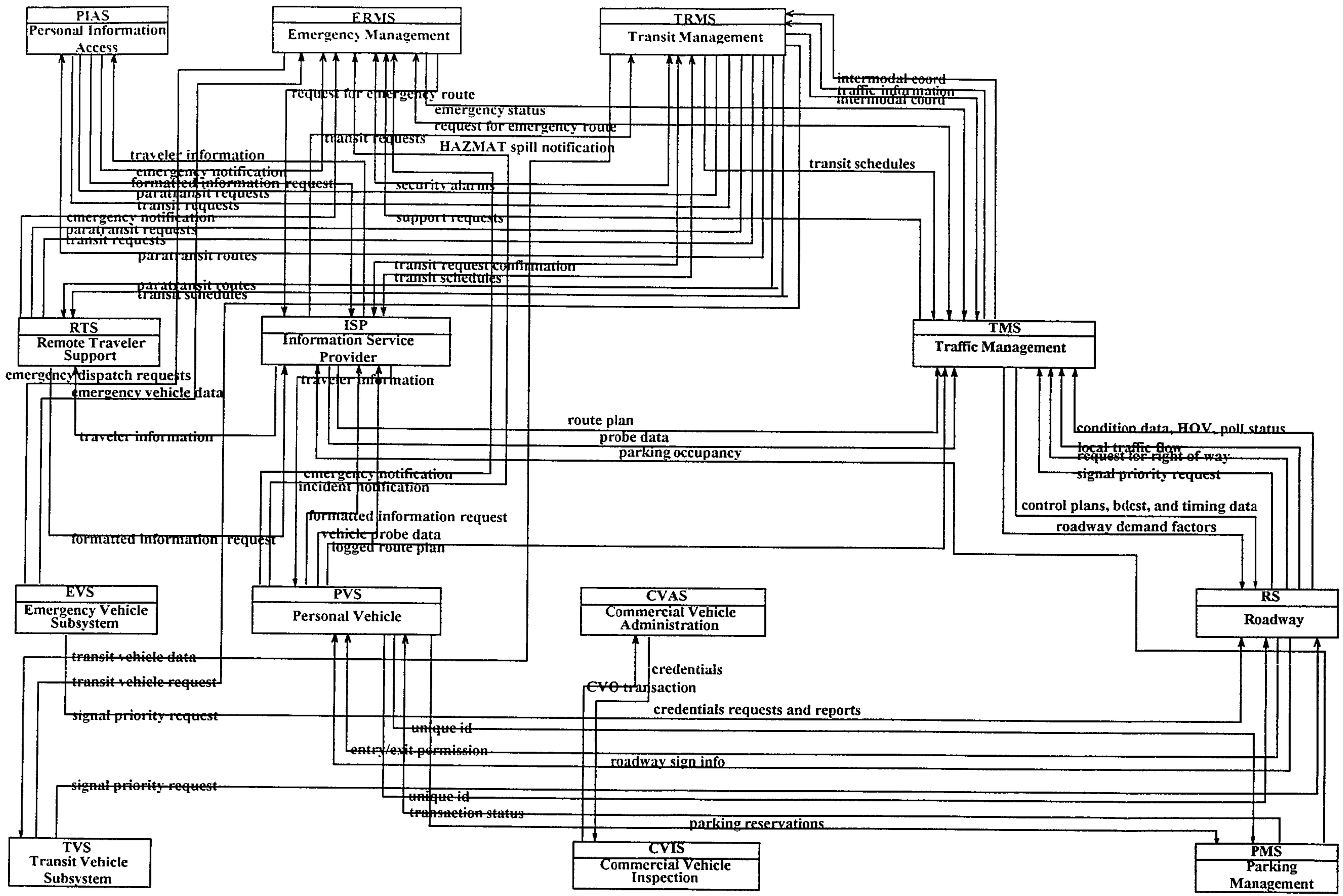


Figure 4-2 Grand Rapids Subsystems and Data Flows

The following briefly defines these system classes and their appropriate architecture subsystems as necessitated by the above User Services requirements. ITS National Architecture information has been derived from FHWA's ITS Architecture, Physical Architecture document.

Center-Class Subsystems

The "center" class subsystems provide management, administration, and support functions for the transportation system. By communicating to other center subsystems any relevant information gathered from center controlled roadside and vehicle subsystems. they enable regional coordination across jurisdictional boundaries and between transport modes.

Traffic Management Subsystem

The Traffic Management Subsystem, usually operating within a traffic management center or other fixed location, monitors and manages traffic flow via communications with the Roadway Subsystem and other Traveler Subsystems. It can coordinate traffic information and control strategies in neighboring jurisdictions, monitor and manage maintenance work. disseminate maintenance work schedules and road closures, manage reversible lane facilities, and process probe vehicle information. This subsystem also supports HOV lane management and coordination, road pricing, and other demand management policies that can alleviate congestion and influence mode selection. When incidents are detected and verified, appropriate incident information is provided to the Emergency Management Subsystem, to travelers (through Roadway Subsystem Highway Advisory Radio and Variable Message Signs), and to third party providers. Finally, the Traffic Management Subsystem provides capabilities necessary to exercise control over those devices utilized for AHS traffic and vehicle control.

Emergency Management Subsystem

The Emergency Management Subsystem, operating in various emergency centers that support public safety (including police and fire departments, search and rescue special detachments, and HAZMAT response teams), interfaces with other Emergency Management Subsystems to support coordinated emergency response involving multiple agencies. The subsystem creates, stores, and utilizes emergency response plans to facilitate coordinated response, and tracks and manages emergency vehicle fleets using automated vehicle location technology and two way communications with the vehicle fleets. Interfaces with the Traffic Management Subsystem allows strategic coordination in tailoring traffic control to support en-route emergency vehicles, and interfaces with the Transit Management Subsystem allows coordinated use of transit vehicles to facilitate response to major emergencies. In addition, real-time traffic information received from the other center subsystems is used to further aide emergency dispatchers in selecting the appropriate emergency vehicle(s) and routes that will provide the most timely response.

Commercial Vehicle Administration Subsystem

The Commercial Vehicle Administration Subsystem, usually operating at one or more fixed locations within a region, issues credentials. collects fees and taxes, and performs the necessary administrative functions to support the enforcement of relevant credentials, tax, and safety regulations. This includes coordination with other cognizant authorities for the receipt of applications and the issuance of special

Oversize/Overweight and HAZMAT permits. This subsystem communicates with individual motor carriers' Fleet Management Subsystems to process credentials applications and collect fuel taxes, weight/distance taxes, and other taxes and fees associated with commercial vehicle operations. This subsystem supports communications with Commercial Vehicle Inspection Subsystems and the dissemination to qualified stake holders of collected, processed. and stored safety information for credentials checking and the identification of carriers and drivers that operate unsafely. It also coordinates with other Commercial Vehicle Administration Subsystems (in other states/regions) to support nationwide access to credentials and safety information for administration and enforcement functions.

Information Service Provider Subsystem

This subsystem provides the capabilities to collect, process, store, and disseminate traveler information such as basic advisories, real time traffic condition and transit schedule information, yellow pages information, ride matching information. and parking information to subscribers and the public at large. The subsystem also provides the capability to provide specific directions to travelers by receiving origin and destination requests from travelers, generating route plans, and returning the calculated plans to the users. In advanced implementations, reservation services are also provided. The subsystem provides the capability for an informational infrastructure to connect providers and consumers, and gather needed market information to assist in service improvement planning and operations maintenance. Available communications links, such as basic one-way (broadcast) and personalized two-way links, provide information to the traveler via the Personal Information Access Subsystem, the Remote Traveler Support Subsystem, and various Vehicle Subsystems

Transit Management Subsystem

The Transit Management Subsystem provides the capability for determining accurate ridership levels, implementing corresponding fare structures, supporting travelers using a fare medium applicable for all surface transportation services, providing for optimized vehicle and driver assignments, and providing for vehicle routing for fixed and flexibly routed transit services. An interface with traffic control can allow for integration with traffic signal prioritization for transit schedule adjustments, and the transit vehicle maintenance management can be automated with schedule tracking. The Transit Management Subsystem also provides the capability for automated planning and scheduling of public transit operations; and can provide the capabilities to furnish travelers with real-time travel information, continuously updated schedules, schedule adherence information, transfer options, and transit routes and fares. In addition, the capability to monitor key transit locations with both video systems, audio systems, and traveler activated alarms, can be provided such that system operators and police are automatically alerted regarding any potential incidents.

Roadside-Class Subsystems

These infrastructure subsystems, governed by and connected to one or more of the center subsystems, provide interfaces to support operations and other functions that require data distribution to the roadside for direct surveillance, information provision, and control plan execution. Direct user interfaces to drivers and transit users, and short range interfaces to the vehicle subsystems are also generally included.

Roadway Subsystem

This subsystem includes traffic control and monitoring equipment that are distributed along roadways, such as highway advisory radios, variable message signs, cellular call boxes, vehicle loop detectors, signals, freeway ramp metering systems, and CCTV cameras and video image processing systems for incident detection and verification. Also provided are capabilities for emissions and environmental condition monitoring, and HOV and reversible lane management functions. In advanced implementations, this subsystem supports the monitoring and communications functions of automated vehicle safety systems that control access and egress to and from an Automated Highway System. This includes systems such as intersection collision avoidance that determine the probability of a collision in the intersection and then send appropriate warnings and/or control actions to the approaching AHS-equipped vehicles.

Commercial Vehicle Inspection Subsystem

The Commercial Vehicle Inspection Subsystem supports automated vehicle identification at mainline speeds for credential checking, roadside safety inspections, and weigh-in-motion using two-way data exchange. Also included are supplemental inspection services that support expedited brake inspections, the use of operator hand-held devices, the enrollment of vehicles and carriers into a pre-clearance program, and access/examination of on-board and historical safety databases. Warnings capabilities are also provided to notify commercial vehicle drivers, their fleet managers, and proper authorities of any safety problems that have been identified and that may influence any decisions as to whether or not to automatically allow the vehicle to pass or to require it to stop with operator manual override.

Parking Subsystem

The Parking Subsystem supports capabilities to provide parking availability and parking fee information, allows for parking payment without the use of cash (i.e. multiple use medium), and supports the detection, classification, and control of vehicles seeking parking. This function may be important to the Grand Rapids area to assist in traffic management near the stadium and arena complexes.

Vehicle-class Subsystems

These vehicle-based subsystems communicate with the roadside subsystems and center subsystems to provide general driver information, vehicle navigation, and advanced safety system functions. It should be noted that general traveler information and vehicle safety functions, as detailed in the Personal Vehicle Subsystem section below, are also applicable to the three fleet vehicle subsystems (Commercial Vehicle Subsystem, Emergency Vehicle Subsystem, and Transit Vehicle Subsystem). The fleet vehicle subsystems also include vehicle location and two-way communications functions that support efficient fleet operations, in addition to various special functions that support their specific service areas.

Personal Vehicle Subsystem

Residing in a personal automobile and providing the sensory, processing. storage. and communications functions necessary to support efficient, safe, and convenient travel by personal automobile, the Personal Vehicle Subsystem uses both one-way communications options (i.e. low-cost broadcast facilities) and two-way communications options (i.e. advanced pay for use personalized information systems) to support a spectrum of information services that provide drivers with current travel conditions and the availability of services along a given route and at a particular destination. Route guidance capabilities assist in formulating both an optimal travel route and step by step guidance along that route. Advanced sensors, processors. enhanced driver interfaces, and actuators complement the driver information services so that in addition to making informed mode and route selections, the driver travels these routes in a safer and more consistent manner. Furthermore, initial collision avoidance functions can provide "vigilant co-pilot" driver warning capabilities. When unavoidable collisions do occur. pre-crash safety systems can be deployed and emergency notification messages can be issued. In the future, more advanced functions may assume limited control of the vehicle to maintain safe headway. Ultimately, this subsystem supports completely automated vehicle operation through advanced communications with other vehicles in the vicinity and in coordination with the supporting Automated Highway System infrastructure subsystems.

Emergency Vehicle Subsystem

Residing in an emergency vehicle and providing the sensory, processing, storage, and communications functions necessary to support safe and efficient emergency response, the Emergency Vehicle Subsystem interacts with the Emergency Management Subsystem to support coordinated responses to emergencies. Using two-way communications and automated vehicle location equipment, appropriately equipped emergency vehicles are able to be monitored by vehicle tracking and fleet management functions in the Emergency Management Subsystem so that the proper emergency response vehicle can be determined. In addition, route guidance and traffic signal preemption capabilities can be added to further enable safe and efficient routing to an emergency via communications with the roadside subsystem.

Transit Vehicle Subsystem

Residing in a transit vehicle and providing the sensory, processing, storage. and communications functions necessary to support the safe and efficient movement of passengers, the Transit Vehicle Subsystem interacts with the Transit Management Subsystem to collect accurate ridership levels, support electronic fare collection. relay transit vehicle maintenance data, and integrate automated vehicle location functions that enable more efficient operations. The Transit Vehicle Subsystem also furnishes travelers with real-time travel information, continuously updated transit schedules, transfer options, routes, and fares. In addition, an optional traffic signal prioritization function can communicate with the roadside subsystem to improve transit on-schedule performance.

Traveler Class Subsystems

The traveler subsystems include general purpose equipment that is typically owned and operated by the traveler, such as personal computers, telephones, personal digital assistants (PDAs). televisions, and any other communications-capable consumer products that can be used for gaining access to information that can be supplied to a traveler within the scope of the ITS architecture. These subsystems interface to the information provider, usually one of the center subsystems (most commonly the Information Service Provider Subsystem), in order to access the traveler information. A range of service options and levels of equipment sophistication are considered and supported.

Personal Information Access Subsystem

This subsystem provides the capabilities for travelers to receive formatted traffic advisories from the infrastructure at fixed locations such as homes, workplaces, and other major trip generation sites; and via multiple types of electronic media at mobile locations such as mobile information centers or within individual vehicles. Included is basic route-planning information that allows users to select those transportation modes that avoid congestion, and in more advanced systems. travel information that allows users to specify those transportation parameters that are unique to their individual needs. Also provided are capabilities to initiate a distress signal, and to cancel a prior issued manual request for help.

Remote Traveler Support Subsystem

This subsystem uses kiosks and other informational displays that support varied levels of interaction and information access to provide traveler information at transit stations, transit stops, other fixed sites along travel routes, and at major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theaters. For example, at transit stops, simple displays providing schedule information and imminent arrival signals can be provided. This basic information may be extended to include yellow pages information, and multi-modal information regarding traffic conditions and transit schedules to support mode and route selection at major trip generation sites -- including personalized route planning and route guidance information based on criteria supplied by the traveler. In addition, this subsystem supports fare card maintenance, public safety monitoring using CCTV cameras or other surveillance equipment for emergency notification within these public areas. and other features to enhance traveler convenience that may be provided at the discretion of the deploying agency.

Design Alternatives

Introduction

With the National Architecture defining what information is processed and where the information flows, various designs that are bounded by the architecture can be evaluated. The three design alternatives provided in this document are based on operational scenarios that are viable for the Greater Grand Rapids area. The basic premise of all three designs is that sensor information (volume, speed, occupancy, video, device status, etc.) from the roadway will be gathered and analyzed either manually or via computer algorithms in order to assess current roadway status and/or determine if there is an incident. In addition to just being of value to the traffic management function, this information is also valuable to emergency management, transit management, commercial vehicle operations, and the traveling public. Looking at the "how" of information flows and processing are the focus of these design alternatives.

Characteristics

The design alternatives are best described by looking at distinguishing characteristics, since all three provide the same basic functionality. These characteristics are detailed in the following text, and summarized **in** Table 4-l.

Table 4-l. Design Alternatives

DESIGN CHARACTERISTIC	ALTERNATE-A: CENTRALIZED	ALTERNATE-B: DISTRIBUTED	ALTERNATE-C: HYBRID
Level of Coordination:	Tightly Coupled; Traffic, Emergency, & Transit Management	Decoupled; Independent Traffic, Emergency, & Transit Management	Tightly Coupled Traffic & Emergency Management; Independent Transit;
Control Logic:	Centralized	Distributed	Distributed
Data Processing:	Centralized: Tightly coupled computer system	Distributed; Very loosely coupled computer systems	Distributed; Tightly coupled for Majority of Processing and Data; Loosely coupled with Transit
Operations Impact:	Common staff to handle multiple functions	Independent staffs specialized for specific functions	Traffic and Emergency functions shared but Transit staff separate
Arterial Signal Control:	Centralized	Centralized	Centralized
Communications Network Complexity:	Simplified: Data flows to a Central Point for All	Complex: Data delivered to multiple locations; Information shared to multiple locations	Medium Complexity: Key Incident and roadway status centralized; Information shared with Transit

Levels of Coordination

Levels of Coordination are characterized by the inherent synergy of the three key management functions: traffic, emergency, and transit.

- Alternative A consolidates all three under a common umbrella or operations center.
- Alternative B provides a very high degree of independence among the three functions, assuming they are geographically dispersed.
- Alternative C couples traffic and emergency, while allowing transit to be independent.

It should be noted that in Alternative C, emergency services, rather than transit, was selected to be coupled with traffic because there is a common “hours of operation” factor between the two of them. Traffic on the roadway is continuous, and emergency personnel are available 24 hours a day in call-answering and dispatch facilities. Transit, on the other hand, normally has a specific operational period that is a subset of a day, and even more limited on the weekends and holidays, when travelers are still on the roadways.

Control Logic

Control Logic focuses on where the responsibility and capability to control the functions exist.

- Alternative A centralizes the control of traffic, emergency: and transit resources.
- Alternative B maintains the independence of each function to control its own assets.
- Alternative C couples Traffic and Emergency to a single point of control, and maintains a sharing of information with Transit, while it continues to control its own.

Data Processing

Options considered include centralized data processing, where most of the data is processed at the central server in the operations center, or distributed data processing, where much data is processed in the field, some control decisions are automatically made in the field based on the results of field-processed data, and mostly processed data is returned to the operations center.

Advantages of decentralized data processing are that it reduces the amount of data required to be communicated to the functional centers, and decreases the processing loads on the central server(s). Distributed processing may also imply increased reliability, because the system is less dependent on the central server. Disadvantages of distributed data processing are that any increases in reliability due to increased redundancy with respect to data processing, communications. and control capabilities usually result in an associated cost increase. Furthermore, there may be increased maintenance requirements due to the equipment not being located in a single location.

Operations Impact

Centralizing transit, traffic, and emergency operations has impacts on the facilities required and the integration of existing operations. As laid out in Alternative A, all agencies must be in agreement in funding initial startup and continued operating costs; however, economies should be realized in the staffing and operations personnel required to run the system. Alternative B maintains the existing "stovepipe" operations and does not derive any economies from overlapping tasks and responsibilities. Alternative C provides the synergy between traffic and emergency for incident detection, verification, response, and management. The close working relationship should expedite the response to incidents and effect control measures to minimize the impacts of the incident by notifying travelers via highway advisory radio or changeable message signs. Via communications, transit would be provided information on incidents so that dispatchers could evaluate contingency plans if routes are affected.

Arterial Signal Control

Signal system management is of particular importance on arterials that might be used for traffic diversion away from freeways following an incident. Grand Rapids does not have a significant number of freeways that may serve as primary alternate routes, so arterials are normally impacted by any significant incident requiring re-routing of traffic. Since the Grand Rapids area has consolidated the operations of the signals under the City's control, arterial signal control does not present a significant problem in providing control or control information (e.g. expected demand) and having the timing plans updated during a major incident.

Communications Network Complexity

While the three designs are independent of the communications transmission system, there are differing levels of complexity associated with each of the following.

- In Alternative A, all data and information flow into a centralized system and the sharing of information is very collapsed into this single location.
- Alternative B is more complex since each function requires and maintains its own communications network to its assets, and an additional network is required to support the sharing of information.
- In Alternative C, the traffic and emergency data share a common network with limited amounts of information (incident information) being shared with transit. This minimizes the complexity and capacity aspects of the communications network.

Fiber optics is the communications media of choice normally because it provides adequate capacity for most ITS applications, and has been proven in applications in other urban areas. While it does represent a major initial investment, it provides needed infrastructure into the foreseeable future for roadside subsystems such as detection and surveillance. Also, since most municipalities are located along the freeway system, any communication network would be a candidate for providing high-speed, high-capacity connections to them. In addition, it should be noted that the recently deployed trunked radio system will still be viable for mobile communications such as emergency vehicle management.

The US 131 corridor provides a linear physical topology. A high capacity fiber optic ring could be deployed by routing fiber up one side of the roadway and then back down the other. While the ring provides a level of fault tolerance in this configuration, it does double the costs for material and installation. Given the limited mileage of roadways in the Grand Rapids area (as compared to Metropolitan Detroit) the ITS Early Deployment Strategic Plan should look at interim use of circuits available from Michigan Bell/Ameritech as a first stage use. For this analysis though the project team will cost fiber optics so that planners may have a better understanding of costs as the system evolves both functionally and geographically. This takes under consideration the evolution of the system along I- 196 and I-96.

Alternatives Evaluation

Introduction

Each of the three design alternatives presented will accommodate the implementation of all User Services that have been identified by representatives of the agencies participating in this study for priority implementation in the Grand Rapids metropolitan area (see Chapter 3). These User Services include: Traffic Control, Incident Management, Hazardous Material Incident Response, Emergency Vehicle Management, Emergency Notification and Personal Security, En-Route Driver Information, Pre-Trip Travel Information, Public Travel Security, Demand Management and Operations, Route Guidance, Public Transportation Management, On-Board Safety Monitoring, Traveler Services Information. Ride Matching and Reservation, Commercial Vehicle Electronic Clearance, Automated Roadside Safety Inspection, En-Route Transit

Information, Personalized Public Transit, Freight Mobility, Commercial Vehicle Administrative Processes, Electronic Payment Services, and Emissions Testing and Mitigation. In addition, because each design incorporates features compatible with the National ITS Architecture, all alternatives will be able to accommodate the implementation of any combination of the other seven non-priority User Services when, and if. they are ever deemed appropriate for implementation in the Grand Rapids metropolitan area.

Evaluation Criteria

Even though each of the three design alternatives are equivalent from the perspective of satisfying User Service requirements, it is still necessary to determine which one implements the User Service requirements most efficiently, and most effectively. To do this, the design alternatives were analyzed for cost, system availability, flexibility, expandability, potential for staged deployment, potential for arterial diversion, and institutional considerations. Additional detail regarding these seven evaluation categories are discussed in the following subsections. Table 4-2 summarizes these details into a list of sixteen specific evaluation criteria.

Table 4-2. Evaluation Criteria

EVALUATION CATEGORY	SPECIFIC DETAILS
cost:	Initial cost for equipment, installation, and software
	Maintenance cost
	Operating cost
System Availability:	Reliability of field equipment
	Reliability of communications network
	Reliability of data processing equipment
	Reliability of operations center software/hardware
	Capability to monitor and control operations in the event of a break in communications capability
	Extent of loss in capability due to a single break in communications capability
Flexibility:	Capability for equipment to operate independently or be controlled by the operations center
	Capability of one agency/jurisdiction to proceed independently of another
Expandability:	Extent to which system can be modified to provide additional capabilities at a later time (e.g. equipment)
	Ease with which the system can be expanded to encompass additional geographic areas
Potential for Staged Deployment:	Ease of incremental implementation with respect to technology, functions, or funding
Potential for Arterial Diversion:	Ease with which an arterial diversion scheme could be implemented, for example, the number of agencies and Traffic Operations Centers that would need to be involved to change signal timing along an alternate route
Institutional Considerations:	Whether design is compatible with existing institutional framework. or whether new agreements would be necessary

Cost

Included were consideration of capital costs, including initial equipment and software costs; the cost for later enhancements to a system; and ongoing costs, namely system maintenance and operating costs.

System Availability

included were consideration of the reliability of the field equipment, the communications equipment, and the data processing equipment (i.e. expected failure rates); the impacts that result from equipment failures; and the capability of a system to accommodate equipment failures based on a system's level of redundancy.

Flexibility

Included were consideration of both the capability of system functions to be operated independently of the center, and for one agency/jurisdiction to proceed independently of another agency/jurisdiction.

Expandability

Included were consideration of technological expandability for the inclusion of still-to-be-developed components in the future, as well as geographic expandability to encompass additional corridors or extensions of existing corridors.

Potential for Staged Deployment

Included were the ease with which a proposed design could be implemented in discrete but operable segments over a period of time, including the ability to add additional ITS functions (i.e. automatic vehicle location and automatic vehicle identification, etc.) at a later date. For example, a project may be segmented with respect to either geography, with certain corridors operational prior to others; or with respect to technology, with more advanced equipment being implemented as justified by changes in operating conditions, or as additional funding becomes available.

Potential for Arterial Diversion

Included were a system's ability to facilitate the implementation of an arterial diversion scheme, the ease with which an arterial diversion scheme could be implemented, and the effectiveness of such an arterial diversion response. For example. capabilities for arterial diversion will usually depend on the operating agreements with local jurisdictions, as well as the sophistication of the signal control equipment on the affected arterials.

Institutional Considerations

Included was the feasibility of a system to be implemented with respect to non-technical/ jurisdictional considerations. For example, a system that is technically satisfactory will be of no benefit if it cannot be implemented due to institutional obstacles.

Evaluation Methodology

Evaluating alternatives based on a single evaluation criteria is usually a straightforward process. For example, comparing:

- The *cost* of Product-A vs. the *cost* of Product-B
- The *reliability* of Product-C *vs.* the *reliability* of Product-D
- The *expandability* of Product-E *vs.* the *expandability* of Product-F

However, when needing to evaluate alternatives based on *multiple* evaluation criteria, which is the case in this study, the relative importance of each individual evaluation criteria with respect to each of the other evaluation criteria should be considered. For example:

- Should more emphasis be placed on system availability, even if it might mean choosing a more costly alternative?
- Should twice as much emphasis be placed on expandability, as is placed on cost or reliability?
- Should all evaluation- criteria be weighted equally?

Utility/Cost Analysis Method

Utility/Cost analysis is a procedure commonly used in situations such as this where it is necessary to evaluate alternatives based on multiple evaluation criteria; especially, when evaluations must simultaneously include both qualitative and quantitative criteria (i.e. monetary and non-monetary items). In this context:

- A “utility” is a measure of value, much like either the concepts “benefit” or “effectiveness”. However, unlike those concepts, it is considered as a proxy measure of value because it is simply a dimensionless number scaled between zero (lowest or least effective) and ten (highest or most effective) that has meaning only when compared to a competing system’s utility.
- A “cost” is an actual monetary value, usually defined as the annualized cash flow for the capital, operating, and maintenance costs of a project throughout its entire design life. It should be noted that costs can also be incorporated as an additional qualitative “utility” value.

Procedure Overview

Essentially, the procedures for a Utility/Cost analysis consist of the following:

- Identify the alternatives to be evaluated
- Identify the goals/criteria that will be used to evaluate the identified alternatives
- Determine the relative weighting values to be assigned to each criteria as compared to each of the other criteria in the analysis
- Assign “utility” values on a scale of one (lowest) to ten (highest) that reflect the extent to which each alternate design achieves each of the above-identified evaluation goals/criteria
- Calculate the total weighted utility value for each alternative.

The resultant weighted utilities for each alternative to be considered are then divided by the cost of that particular alternative (usually consisting of annualized capital costs plus any annual operating and maintenance costs). The resulting value is then considered the "Utility/Cost Factor" (UCF). The higher this value, the more likely the associated alternative better satisfies the various multiple evaluation criteria, and thus should more likely be chosen as the preferred alternative.

Utility Factor Development

To represent the extent to which design alternatives were expected to satisfy each of this study's sixteen specific evaluation criteria (see Table 4-2), the study team calculated sixteen Utility Factors (u_{ij}) for each of the three design alternatives, and for each of the three implementation time-frames under consideration: short-term. medium-term, and long-term. Utility values range from zero to ten. Zero is indicative of the least utility or benefit, five is indicative of an average utility or benefit, and ten is indicative of the highest utility or benefit. With the exception of utility factors for cost (described in additional detail below), ail utility factors were qualitatively determined. The following subsections discuss methodologies used to assign utility values to each alternative, and highlight design characteristics that affected what utility values were actually assigned to each design. Table 4-3 summarizes the utility values assigned to each of the design alternatives.

Cost

The utility factors representing cost are scaled values based on the estimated dollar costs for each alternative (see Appendix C). Cost utilities were calculated by first expressing the dollar cost of each alternative as a percentage of the dollar cost of the most expensive alternative for the particular cost evaluation criteria being considered. These proportions were then subtracted from one, with the resultant values multiplied by ten in order that they may be scaled to values between zero (lowest utility) and ten (highest utility).

For example, given three alternatives that may cost $5 (Alternate X), $10 (Alternate Y), and $20 (Alternate Z), they would be scaled as follows:

- Alternate X: { [1 - ($5/$20)] *10 } = 7.5 (high utility since cheapest)
- Alternate Y: { [1 -($10/$20)] * 10 } = 5
- Alternate Z: { [1 - ($20/$20)] * 10 } = 0 (low utility since expensive)

Table 4-3 Utility Values Assigned to Each Alternate Design

Evaluation Criteria		Short-Term			Medium-Term			Long-Term		
	Design Alternatives:	A	B	C	A	B	C	A	B	C
Cost										
u_1	Capital cost	5.3	5.5	5.4	2.9	3.0	2.9	0.1	0.1	0.0
u_2	Maintenance cost	6.3	8.8	7.5	3.8	7.5	5.0	0.0	6.3	2.5
u_3	Operating cost	5.4	6.1	5.7	2.9	3.4	3.4	0.0	0.8	0.4
System Availability										
u_4	Field equipment reliability	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
u_5	Comm. network reliability	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
u_6	Data processing equipment reliability	5.0	7.0	7.0	5.0	7.0	7.0	5.0	7.0	7.0
u_7	Operations center software/ hardware reliability	7.0	8.0	7.5	7.0	8.0	7.5	7.0	8.0	7.5
u_8	Capability to monitor & control operations in the event of a break in comm. capability	3.0	8.0	7.0	4.5	8.5	7.5	6.0	9.0	8.0
u_9	Extent of loss in capability due to a single break in communications capability	3.0	7.0	7.0	4.5	7.5	7.5	6.0	8.0	8.0
Flexibility										
u_{10}	Capability for equipment to operate independently or be controlled by the operation center	3.0	8.0	8.0	3.0	8.0	8.0	3.0	8.0	8.0
u_{11}	Capability of one agency/ jurisdiction to proceed independently of another	4.0	10.0	9.0	4.0	10.0	9.0	4.0	10.0	9.0
Expandability										
u_{12}	Extent to which the system can be modified to provide additional capabilities at a later time (i.e. equipment)	5.0	8.0	8.0	5.0	8.0	8.0	5.0	8.0	8.0
u_{13}	Ease with which system can be modified to encompass additional geographic areas	5.0	7.0	7.0	5.0	7.0	7.0	5.0	7.0	7.0
Staged Deployment										
u_{14}	Potential for staged deployment	4.0	8.0	8.0	4.0	8.0	8.0	4.0	8.0	8.0
Arterial Diversion										
u_{15}	Potential for arterial diversion	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Institutional Considerations										
u_{16}	Potential for implementation with minimum institutional barriers	3.0	8.0	7.0	3.0	8.0	7.0	3.0	8.0	7.0

System Availability

The utility factor representing system availability varies depending on the control logic, the data processing, the number of operations centers, and the geographic extent of the system (interim or ultimate). Multiple server control logic and multiple operations centers are considered more reliable, because if one server or operation center goes down, the remaining server or operations center might be able to assume some of the functions of the server or operations center that is unavailable. Even if this redundancy does not exist, only the portion of the system that relied on the single server or operations center would be down, rather than the entire system. With respect to data processing, distributed data processing is considered more reliable since field data processing can continue to some extent even when central processing capabilities are restricted. Finally, with respect to the geographic extent of the system, the ultimate system would be more reliable because the loop communications configuration would provide more possible routes for information flow which would provide additional redundancy and minimize the impact of an equipment malfunction or break in communications. Overall, system availability of a given design alternative tends to increase as component redundancy increases, and as the number of alternate communications routes increases.

Flexibility

The utility factor representing flexibility varies depending on the data processing (which impacts the capability to operate the field equipment independently of the central server), and the level of centralization (which impacts each agency/jurisdictions' ability to proceed independently). The level of centralization is defined not only by the number of activities and agencies included in the operations center (transit, emergency responders, etc.), but also by the number of operations centers, and the control logic.

Expandability

The utility factor representing expandability is affected by the capacity of central control, as well as the communications network and the data processing. Because all alternatives have fiber optics as the basis for communications, and assuming all systems have similar available capacity with respect to central control, distributed data processing would facilitate expandability because data processing capacity can be added as needed when additional field equipment is implemented.

Potential for Staged Deployment

The utility representing staged deployment varies depending on the degree of centralization of the data processing. A more centralized system would be more difficult to deploy in stages, due to the fact that a larger number of agencies would have to be coordinated. Decentralized data processing is more conducive to staged deployment because data processing equipment can be installed concurrent with the staged expansion.

Potential for Arterial Diversion

The utility representing the ease with which arterial diversion could be implemented is based on the extent to which arterial signal systems on major alternate routes are controlled by a traffic operations center and/or other computerized system.

Institutional Considerations

The utility representing the feasibility of each architecture with respect to institutional considerations is affected by the level of centralization, the number of operations centers, and the control logic. With respect to the level of centralization, in a more distributed design. institutional issues tend to be related to who "owns" various pieces of data, what data will be shared, and how often that data will be shared; whereas, in a more centralized design, potential institutional issues tend to relate to how *responsibilities* are ultimately shared, since personnel often do multiple functions. Ultimately, though, institutional considerations relate to the extent to which a design is compatible with the existing institutional frameworks, or if new ones need to be created.

Weighting Factor Development

To determine the appropriate weighting factors (k-values) to apply when performing the Utility/Cost analysis, a short survey (see Appendix B) was handed-out to all members of the Project Advisory Committee at their December 12, 1995 meeting. Their task was to "spend" a total of 100 points on the above seven evaluation criteria categories, such that the number of points "spent" on each category reflected the relative value that they placed on each particular category. Table 4-4 summarizes the Mean values of these committee responses, and the k-values that the study-team used to perform this analysis (calculated as the mean value of a specific evaluation criteria, multiplied by the mean value of its associated evaluation category, then all divided by. 100). Detailed responses can be found in Appendix C. Note that the sum of all k-values must be equal to 100 percent.

Analysis and Results

Calculations

The overall Utility **(Ui)** of each design alternative is calculated as the sum of each designs' sub-utilities relative to each of the sixteen individual evaluation criteria (u_{ij}-factors), weighted to reflect the appropriate priorities that have been assigned to them by the Steering Committee (kj-factors). Thus, for each design alternative in this study (I):

$$U_i = k_1 u_{i1} + k_2 u_{i2} + k_3 u_{i3} + \ldots + k_{15} u_{i15} + k_{16} u_{i16}$$

Results of these calculations are summarized in Table 4-5.

Next, the Utility-Cost Factor **(UCF_i)** for each design alternative was computed as the overall Utility for a design **(U_i),** divided by the annualized cost for that design (C_i).

$$UCF_i = U_i / C_i$$

Results of these calculations are also summarized in Table 4-5. It should be noted that in addition to the cost of each design alternative entering the analysis as the above formula's denominator, the cost of each design alternative was also taken into account as a utility criteria in this formula's numerator (with lower cost resulting in higher utility).

Table 4-4 k-Values Used for Each Evaluation Criteria

Evaluation Category	MEAN	Evaluation Criteria Weightings	MEAN	k-Factor Weighting	Value
Cost:	20.7	Initial cost for equipment, installation, and software	33.3	k_1	6.9
		Maintenance cost	33.3	k_2	6.9
		Operating cost	33.3	k_3	6.9
		TOTAL:	99.9		
System Availability:	17.1	Field equipment reliability	16.7	k_4	2.9
		Communications network reliability	16.7	k_5	2.9
		Data processing equip. reliability	16.7	k_6	2.9
		Operations center software/ hardware reliability	16.7	k_7	2.9
		Capability to monitor and control operations in the event of a break in communications capability	16.7	k_8	2.9
		Extent of capability loss due to a single break in comm. capability	16.7	k_9	2.9
		TOTAL:	100.2		
Flexibility:	12.9	Capability for equipment to operate independently or be controlled by the operations center	50.0	k_{10}	6.4
		Capability of one agency to proceed independently of another	50.0	k_{11}	6.4
		TOTAL:	100.0		
Expandability:	14.7	Extent to which system can be modified to provide additional capabilities at a later time	50.0	k_{12}	7.4
		Ease of system expandability to additional geographic areas	50.0	k_{13}	7.4
		TOTAL:	100.0		
Potential for Staged Deployment	12.4	Incremental implementation ease, i.e. technologies, functions, or cost	100.0	k_{14}	12.4
		TOTAL:	100.0		
Potential for Arterial Diversion:	11.4	Implementation ease & # of TOCs/ agencies needed to change signal timings along an alternate route	100.0	k_{15}	11.4
		TOTAL:	100.0		
Institutional Issues:	10.7	Is design compatible w/institutional framework or are new ones needed	100.0	k_{16}	10.7
		TOTAL:	100.0		
TOTAL:	100.0			TOTAL:	100.0

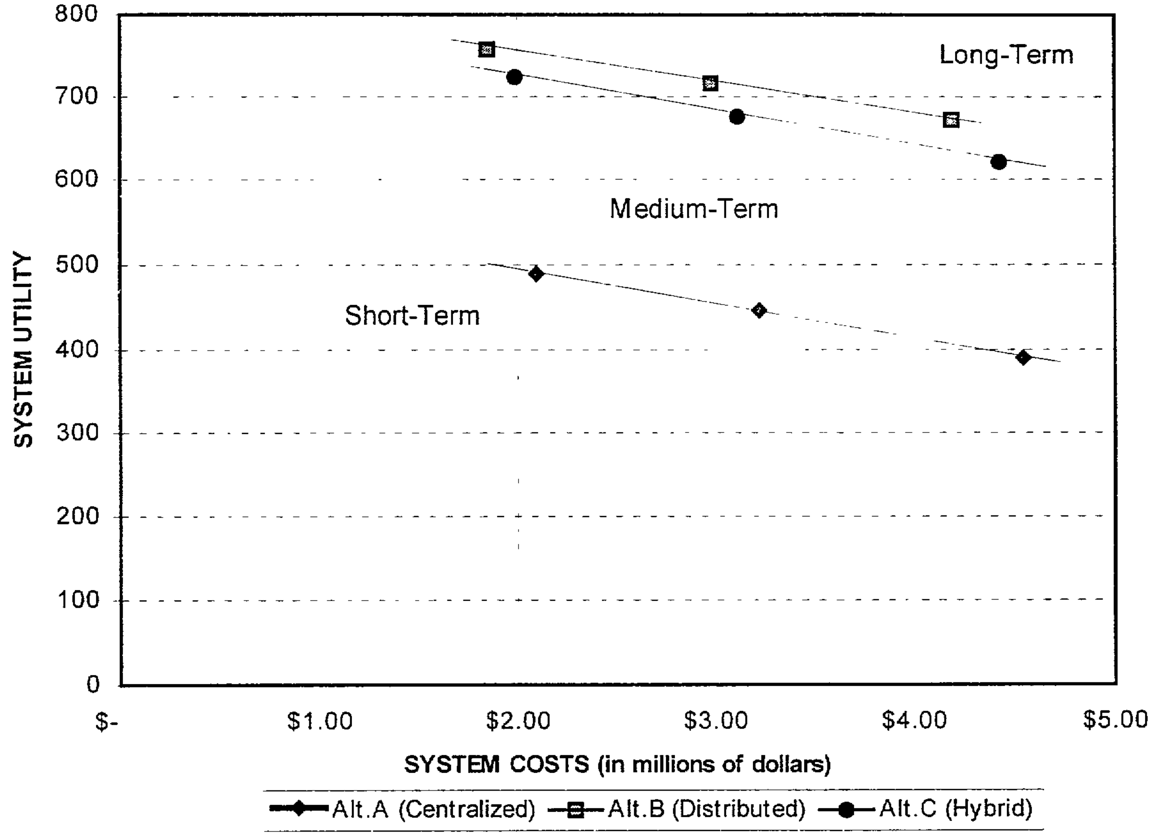
Table 4-5 Summary of Utility/Cost Analysis Results for Each Alternative

	Short-Term			Medium-Term			Long-Term		
	A	B	C	A	B	C	A	B	C
Weighted Utility:	480	731	705	451	695	669	401	651	613
Annualized Costs (see Chapter 6):	$2.11	$2.04	$2.12	$2.86	$2.83	$2.90	$3.87	$3.84	$3.97
Utility/Cost Factor:	227	358	333	158	246	231	103	170	154

Results

As presented in Figure 4-3, a Distributed type system implemented in the short term time frame has both the highest utility and the lowest system costs of all alternatives identified in this analysis. Using this as a starting point provides the Grand Rapids Metropolitan area with a high-return baseline system that can evolve over time into a Hybrid type system, or eventually into a Centralized type system, if deemed institutionally desirable, in order to take advantage of increased economies of scale and additional opportunities for agency coordination that can become available as both personnel and activities are consolidated. It must be noted, however, that even though Figure 4-3 indicates declining incremental system utility as more miles are added to the system in later time frames, it should be remembered that since this initial analysis was focused on agency costs, the increased user benefits that tend to accompany the implementation of increased system coverage and additional user services were not included. When area specific user benefits quantified from the implementation of a baseline system become available, their incorporation into a similar analysis can make increasing incremental system utility more readily apparent such that it could indicate needs to implement later term features.

Figure 4-3 System Costs vs. System Utility for Each Design Alternative



Chapter 5
Technologies

TYPES OF TECHNOLOGIES

Surveillance technologies include vehicle detection technologies, closed circuit television (CCTV) and technologies for electronic toll collection (ETC). Vehicle detection technologies include both passive and active technologies. Passive technologies are those that do not require specially equipped vehicles to operate. Passive technologies include standard technologies such as induction loops as well as newer technologies such as microwave detectors. Active technologies include automatic vehicle location (AVL) and automatic vehicle identification (AVI), as well as transponders for ETC.

Communication technologies include fiber optics, which is expected to become the primary medium for communications in Grand Rapids. Other technologies that are discussed within this chapter will potentially be used for the initial system and in areas where fiber optics have not been installed.

Traveler interface technologies are critical since they allow the public to make informed decisions in their travel routes. These technologies include variable message signs (VMS), highway advisory radio (HAR) transmitters, information kiosks, and dial-in information systems such as traveler advisory telephone systems.

Data processing technologies are used to process the data collected by the detectors. This also includes incident detection algorithms which are used to analyze the data to identify incidents.

This chapter also presents various strategies of using these technologies effectively. These strategies include incident detection and verification options, options to improve response time, options for site management, options to reduce clearance time, and options for traveler and motorist information. This leads into the potential improvement recommendations in the last part of this chapter.

SURVEILLANCE TECHNOLOGIES

Advanced Traffic Management Systems (ATMS) typically provide two different sub-systems for roadway surveillance: vehicle detection, and closed circuit television (CCTV). These two subsystems provide different functions, and operate together to provide the traffic operations center (TOC) with real-time status of traffic conditions. The vehicle detection sub-system electronically monitors the flow of traffic on the roadways, and transmits this information in “real-time” to the TOC for analysis and status displays. The operators utilize the results of the analysis and the status information to make decisions regarding management of the traffic. The CCTV sub-system provides the operators with visual means for verification of the conditions reported by the vehicle detection sub-system. The CCTV images also provide the operator with an independent evaluation of traffic conditions.

Each of these two sub-systems can be deployed and utilized jointly as well as separately. However, the complementary interaction of the two sub-systems improves the overall system operation in a manner that neither system can provide alone. The vehicle detection system, since it is automated and can function with minimal human intervention, provides continuous surveillance and up-to-the-minute data. The CCTV system allows the human observer to view and interpret an incident, or other traffic conditions.

and determine an appropriate response. As more progress is made in the technologies of image processing, artificial intelligence. and expert systems, it is inevitable that computer systems will augment the capabilities of the human observer.

Vehicle Detection

Vehicle detection technologies form the foundation of the surveillance sub-system used for automated incident detection and traffic management. Surveillance information provided by vehicle detection enables collection of a range of traffic data including speed, volume, density, travel time, and in some cases, vehicle position. Control strategies, incident management procedures, and motorist information displays are selected based upon the data collected by the vehicle detection system. The collected data is used in real-time for making traffic management decisions and stored to provide a historical data-base of traffic conditions. Surveillance can also be used to obtain information on vehicle classification, length, speed, acceleration characteristics, and hazardous materials.

Operational environment and maintenance requirements are two of the most critical factors in determining the types of detectors for the system. Systems that involve cutting existing road surfaces and pavement (such as induction loops) can create installation and maintenance problems or compromise the structural integrity of the roadway, especially on bridges and other structures. Technologies that do not require these modifications are termed non-intrusive installations, and minimize the traffic diversion and control problems.

The choice of detectors for an automated system is dependent on the data requirements. To meet the needs of the recommended system, real-time data to ascertain vehicle speed, counts, lane occupancy, classification, and changes in motion and position, will be required for automated incident detection. This real-time data should be stored for historical as well as planning use.

There are two separate approaches to vehicle detection; those that are passive and involve no electronics in the vehicle, and those that cooperatively utilize electronics in the vehicle and alongside the roadway. As with all areas of electronic technologies, changes occur regularly which provide new solutions to existing problems, but conversely requiring that systems be flexible enough to accommodate change on a regular basis.

Various technologies applicable to this project are discussed below. There are numerous other technologies that have been experimented with and tested by various departments of transportation and the Federal Highway Administration (FHWA). In particular, the “Detection Technology for ITS” project sponsored by FHWA is evaluating a wide range of equipment under laboratory and field conditions. Although many of these technologies show promise, they have not progressed to reliable field operation. In order to limit system complexity and resultant operations and maintenance costs, minimizing the number of different technologies is preferred.

Passive Vehicle Detection

Technologies that do not require any devices in the vehicle are the basis for most current vehicle detection systems. Passive approaches allow all vehicles in the vicinity of the sensor to be detected and monitored, but provide less information than will ultimately be available in the future.

Induction Loops: The most commonly used vehicle detection technology is the induction loop. This technique is extensively used for arterial controls and has a long history of successful field deployment. The advantages of induction loops are their well-known performance characteristics, maturity, application flexibility, and multiple vendor availability. Over the years the manufacturers have enhanced and refined their equipment, providing numerous options and alternatives to meet a wide range of application needs. Pairs of loops can be used to measure speed and vehicle length for classification purposes. Some vendors have announced products that measure speed with a single loop, but field experience is limited. Some disadvantages of induction loops are the result of the need to embed the loops in the pavement surface, and the problems associated with pavement deterioration and freeze-thaw damage. Further difficulties include damaging the loop conductors during resurfacing operations or construction, and the reduced effectiveness of loops when in close proximity to reinforcing steel.

Recent improvements have been made in inductive loop technology. Loop detectors have been primarily utilized to provide a digital output that is representative of vehicle presence above the induction loop in the pavement. In this regard, a sophisticated computer system is unable to gain access to any information contained in the magnetic or inductive signal collected by the detector amplifier. New products are available with on-board microprocessors that are able to monitor the “signature” of the detected field. Use of this data allows accurate speed measurement and provides some capability for classification. Serial data ports with RS-232 communication, allow systems to access a detector amplifier internal database, to perform remote sensitivity adjustments and compensate for weather conditions.

Another development is the manufacture of pre-formed loops, which are available from a number of suppliers. This type of loop is pre-assembled, with the wires encased in a filled conduit. This assembly is embedded in the pavement. typically several inches below the surface, during the construction of the roadway. This technique offers improved reliability and life expectancy.

A similar approach, that of embedding the loop in the pavement, is being utilized in some areas as part of roadway reconstruction projects. After the old pavement is removed by milling, the induction loop is saw-cut into the milled surface. After the new pavement is applied, the loop is buried several inches below the road surface, where it is less subject to damage from traffic, construction or weather.

While induction loop detectors are often maligned because of the problems noted previously, they are currently the primary source of vehicle detection in most systems around the country. Studies in Los Angeles were performed by video taping the traffic stream, time-stamping and manually counting the vehicles on the video tape. Results show that the accuracy of induction loop data with respect to vehicle counts is $\pm$0.6%.

Magnetometers: Magnetometers, and the related micro-loop technology, are often suggested for deployment on bridges and other areas where loop installation in the existing pavement area could affect structural integrity. Magnetometers have had spotty operational success, and other technologies have often been considered for these particular needs. However, the use of new digital processing technology has the potential to significantly improve the performance of magnetic detectors. A re-evaluation of their role will be appropriate after sufficient field experience is gathered. Preliminary results from the IVHS Detection Technology project show that magnetometers have an accuracy in the $\pm$5% range.

Axle Counters: The FHWA requirement for 13 bin vehicle classification on certain roadways generates the need to count axles. The most commonly used technology uses a bending beam piezoelectric strip embedded in the roadway surface. These devices, working in conjunction with inductive loops, measure the vehicle length and speed, and count the axles. The vehicle length. combined with axle count, are used to classify the vehicle.

Radar: Radar detectors operate by emitting a signal in the microwave portion of the electromagnetic spectrum, and analyze the returned signal. These detectors are in limited use in incident detection and freeway management projects. Continuous Wave (CW) radar detection operates on the Doppler effect (measuring frequency shifts between the transmitted and received beam caused by vehicle motion), and thus directly measures vehicle speed. Vehicle counts can be determined by accumulating each vehicle detected, but this approach cannot readily obtain lane occupancy and vehicle lengths. Similarly, detection of stopped vehicles, or very slowly moving vehicles, is difficult.

Another type of CW radar detector transmits a signal that is swept over a range of frequencies. This technique allows measurement of range from antenna to vehicle, and is thus able to function as a presence detector. The sweep frequency however functions much as sample rate to quantify presence.

Pulsed radar operates by transmitting a burst of microwave energy, and interpreting the “echoes” reflected from vehicles in its “field of view”. Because of the complications involved in processing multiple reflection, pulsed radar units utilized for traffic detection limit their field of view to a portion of the lane, such that a single vehicle is present in their detection zone. This technique permits the determination of the distance to the nearest reflection, and by monitoring this reflection over time, the position and resultant speed of the vehicle can be determined. This type of radar can be used to sense stopped vehicles, but has the limitation of a sample rate that must be frequent enough to provide accurate presence calculations to determine other traffic parameters.

Continuous wave radar detectors of the Doppler and swept frequency types require one antenna per lane, mounted on a structure or a sign bridge over the lane. The same limitation applies to pulsed radar units. Early Results of the IVHS Detection Technology Project show that the accuracy of these radar detectors ranges from ±0.5% to ±6%

The *microwave detector* has recently become available. When mounted at the side of the roadway, this device is able scan up to twelve lanes. Since side mounting facilities are often available, or can be readily installed, the device is more cost effective. The device can also detect vehicle presence, and is thus able to determine occupancy and existence of stopped vehicles. However, it does not measure speed directly, relying upon “single loop” speed estimation techniques based upon average vehicle length. The accuracy of this device, as stated in the early results from the Detection Technology Project. is in the ±5% range for volumes. Test results indicate missed and duplicated counts across multiple roadway lanes upon the passage of large vehicles.

The advantages of radar and microwave devices include the ease of use, requiring no cutting of pavement and disruption of traffic flow for installation or maintenance (if mounted on a structure or sign bridge where overhead access is possible). For the Doppler units, direct speed measurement is a significant benefit. If traffic lanes are shifted, radar antennas can be easily re-aimed. The disadvantages of radar are the overhead mounting requirement, the limited field operational experience for many of the new units, the small number of vendors in the market, and the difficulties of accurately sensing lane occupancy and slow moving or stopped vehicles with Doppler units.

Radar detectors can be configured with two types of interfaces: RS-232 serial data and two pulse-type contacts. The serial output provides data (volume, speed, etc.) in an ASCII text string. Modifications to this format to incorporate an error checking communications in a standardized protocol would allow a multi-lane unit to be installed without a local field microcomputer. The dual pulse-type contact closures provide for emulation of a loop-pair speed trap. The first contact closure occurs when the vehicle enters the detection zone, and the second contact closure is timed relative to the first closure by the detector to provide the correct travel time based upon a calibrated “loop spacing”.

Infrared: Infrared detectors monitor electromagnetic energy in the band above the visible spectrum. Both active and passive devices are marketed that utilize infrared detection.

Active infrared devices illuminate the detection zone with infrared energy supplied by either light emitting diodes (LED’s), or lasers. Lasers can provide a higher level of output energy. A portion of the energy reflected back from the vehicle is detected and processed. The detector consists of optical elements to focus the returned signal onto a matrix of infrared sensors. The two-way travel time of the infrared pulse from the source to the sensors is used to measure the distance to the vehicle. This strategy is similar to that used in a pulsed radar detector. Processing of the data provides vehicle counts, occupancy, presence, speed and classification information. Because infrared energy is attenuated and scattered by rain, snow, fog and mist in the air, active infrared detectors are vulnerable to these atmospheric conditions. In addition, other obscurants in the air, such as smoke and dust, can reduce the effectiveness of the detector.

Passive infrared devices do not emit any energy themselves, but utilize the characteristic that all objects emit heat (infrared radiation) as a function of their surface temperature. The amount of infrared energy is also a function of the energy emitted by the object itself. By detecting difference between the temperature/energy emitted by vehicles and the roadway surface, a passive infrared detector can determine the presence and passage of vehicles. The infrared energy is focused through an optical system onto the infrared sensors. The resultant signal is processed to provide presence, vehicle counts and occupancy. As noted above, infrared energy is obscured by atmospheric effects. Because passive infrared detectors are dependent upon the sun and other infrared sources for their input energy, diurnal changes, cloud cover, glint from bright objects reflecting sunlight, etc. can create confusing and unwanted signals.

By increasing the number of sensors in a passive infrared detector, an “image” of the scene of interest can be generated. This increase in detail allows additional information from the scene to be discerned and analyzed. As the number of individual sensors becomes large enough, the boundary between an infrared detector and an infrared sensitive CCTV camera becomes blurred. For practical applications, an infrared imaging system has essentially all the same characteristics of Video Image Detection systems discussed below.

Sonic: There are several techniques that have been explored utilizing sound. Some devices operate as sonar devices, sending out sound waves and analyzing the returned echoes from the vehicles - much like the radar systems. The early results from the ultra-sonic unit included in the ITS Detector Technology test show an accuracy in the $\pm$2% range. A recent test by the Arizona DOT found that these detectors offer an accuracy in the ±5% range. Other sonic detectors passively “listen” to the noise generated by the vehicles, and analyze this noise energy to detect individual vehicles and resultant location and speeds. These devices have not yet been extensively used, and thus field experience is limited. However the technology has been applied for submarine noise signature detection by the military and could become a valid tool for the classification of vehicles.

Video Image Detection: Video Image Detection (VID) systems (sometimes referred to as machine vision systems) are comprised of fixed orientation CCTV cameras strategically located to provide views of specific areas or long sections of roadway, coupled with a computer that analyzes the video image in real time (30 times per second). This technology has been developed for various industrial, manufacturing, military and aerospace applications. It has been applied to traffic management in recent years, with growing success. Early systems were troubled by harsh environments, adverse and changeable lighting conditions, shadows, differing vehicle shapes, and sometimes difficult operating conditions. These difficulties have, for the most part, been solved by extensive field testing. actual deployment, more powerful computers, and increasingly sophisticated software.

Two fundamentally different strategies are used to analyze the video images: fixed analysis zones that detect vehicles moving through them, and vehicle identification and subsequent tracking. A third strategy, involving reading license plates “on-the-fly” may be appropriate for toll violations and related applications, but is not directly applicable to this Early Deployment Study. The technique utilizing fixed analysis zones, analogous to a “loop” in the video image, is the most stable and best tested approach. Equipment based on this approach can provide vehicle counts, lane occupancy, speeds, and lengths. Software in the VID processor collects the standard information (volume, occupancy, and speed) and can also provide some analysis and processing of this data, including statistics accumulation. data smoothing, and level of service calculations.

A key benefit of a VID system is its ability to monitor large areas of roadway from a single equipment location. Because the CCTV camera can be oriented to monitor a section of roadway (up to 1/4 mile), and the entire image can be analyzed, significantly more roadway and a greater number of vehicles can be monitored. The most promising usage of a VID system is detection of stopped or stalled vehicles (either in a travel lane or on the shoulder), providing direct detection of an incident. The monitoring of wide areas of roadway, coupled with individuai vehicle detection, is expected to provide significantly more information than existing point source (such as induction loop or radar) technologies.

While the promise of VID systems is significant, it is still a young technology that will evolve and grow for many years. There are operational problems under adverse lighting, and during transitions between daylight and darkness (including storm conditions) that require more refinement. Camera placement must be carefully considered, as shadows from objects outside the detection area may affect performance. The early results from the Detector Technology project report show accuracies ranging from ±0.3% to ±2.3%, with accuracy decreasing under dark or adverse weather conditions.

Passive Vehicle Detector Cost Comparisons

Two different categories of passive vehicle detectors are discussed above: those that are embedded in the road surface. such as induction loops, and those that are mounted overhead. such as a radar detector or a video image detector.

As discussed, embedding detectors in the roadway requires that the road surface be cut or drilled, and subjects the detector to failure due to pavement deterioration, etc. This can create ongoing maintenance problems or poor detector reliability. As noted, newer construction techniques which embed the detector several inches below the pavement surface are being used to solve some of these problems.

Detectors that are mounted above each lane, such as most radar detectors and ultrasonic detectors, require some form of support structure. A claimed advantage of this installation location is minimal traffic disruption during installation and maintenance. Mounting on an existing over-crossing is an option, but can create aesthetic concerns and often results in limited accessibility requiring that a traffic lane be closed to service the unit. The use of signal head mast arms is another possibility, but has the drawback of motion under high wind loading and the need to block traffic for installation and servicing. Sign bridges are a third possibility, and where they already exist they are excellent choices, especially if they include a cat-walk so that the units can be installed and serviced without shutting down traffic. However, the installation of new sign bridges for the mounting of detectors is an expensive alternative.

In general terms, many of the overhead detectors cost between $750 and $1000 per unit that monitors a single lane. Poles and mast arms cost about $200 per foot (with foundation and installation), resulting in a cost of roughly $2,400 for a 12 foot lane. This is about 2.5 times the cost of the detector. Sign bridges roughly cost $500 per foot (with foundation and installation), or $6,000 for a 12 foot lane. This is about 6 times the cost of the detector. This needs to be compared to the installed cost of induction loops of about $1,000.

Thus, overhead mounted detectors that must be positioned over each lane can be significantly more expensive than induction loops when the cost of a mast arm and pole or sign bridge must be included. Under those situations where an existing structure or sign bridge is available, they can be cost effective - but may still require traffic disruptions for installation and servicing.

Another category of overhead devices-side fired radar and video image detectors (VID’s) - can be mounted off the side of the road or on a pole in the median. This reduces the cost of mounting to roughly $5,000, and does not require stopping traffic for access to the unit. These devices also have the advantage of being able to monitor several lanes from a single unit, thus spreading the cost of the unit and the mounting pole across several lanes. A disadvantage of side mounting or an oblique camera view is the fact that trucks and larger vehicles may obscure smaller cars through disruption of the line of sight. This results in missed counts. With VID’s, the ability to discriminate between two closely following vehicles is a function of mounting height and angle of view. Increased height improves the discrimination ability, but results in a more costly pole and foundation. Another problem noted with VID’s is motion of the mounting pole under wind loading. or twisting of the pole due to differential solar heating. These conditions result in the camera field of view changing and “moving” the fixed analysis zones to another portion of the image.

For comparison purposes, a six lane cross section of freeway has been utilized. Five different equipment configurations have been evaluated:

- Induction Loops, with lead in wires saw-cut into pavement surface and processor cabinet on one shoulder;
- Side Fired Radar, with unit mounted on a pole located on one shoulder adjacent to the processor cabinet;

- Video Image Detector, with two cameras mounted on a pole in the median and the processor cabinet on one shoulder;
- Overhead Mounted Sensors on Mast Arm with the pole in the median and the processor cabinet on one shoulder; and
- Overhead Mounted Sensors on Sign Bridge with processor cabinet on one shoulder.

For all configurations, it is assumed that power and communications conduits are available at the location of the processor cabinet. With the exception of the video image detector, a Model 170 processor and cabinet is included. Conduit, cable, installation and testing costs are included for all cases. For the two configurations with median located poles (VID and Overhead Sensors on Mast Arm), costs for jacking conduit under three lanes are included.

Table 5-1. Estimated Costs for Passive Vehicle Detection

Configuration	Per Lane	Six Lanes
Induction Loops	$ 3,400	$20,400
Side Fired Radar	$3,725	$22,350
Video Image Detector	$ 10,100	$60,600
Overhead Mounted Sensors on Mast Arm	$ 6,250	$37,500
Overhead Mounted on Sign Bridge	$ 13,250	$79,500

Maintenance costs are usually calculated on an annual basis as 10 percent of the equipment cost. Maintenance costs associated with induction loops may be higher, as indicated by local experience.

Active Vehicle Detection

Technologies that include electronics in the vehicle that interact with the roadside infrastructure and other vehicles in the immediate vicinity appear to be the next step toward automated guidance and highway systems. Although it is expected to be at least two decades before these technologies become widespread, devices in this category are currently being used for specific applications around the country.

Automatic Vehicle Identification: The recent conversion of many toll facilities to electronic toll tags for electronic toll collection (ETC), also referred to as automatic vehicle identification (AVI), creates a potential for vehicle detection and monitoring in some areas. By monitoring the movement of individual vehicles past various AVI antennas, the vehicles become active probes and link travel times can be determined. This technology is successful in areas w-here AVI tags are in use for toll roads, but is of limited applicability elsewhere.

Another implementation of AVI technology is its use on transit vehicles to determine their location. The use of induction loops as the reading antenna has been successfully deployed in some areas. This use of AVI has found a receptive audience as a method for more accurate tracking of bus fleets for control and dispatch.

Global Positioning Systems (GPS): GPS equipment is being used by various emergency and fleet organizations to permit continuous tracking of vehicle locations. The costs per vehicle are still too high for widespread use by the general public, but the technique is very beneficial in those cases where it can be justified. Accuracies range from a few hundred feet to a few feet, depending upon the capabilities of the GPS receiver. The more accurate units are proportionally more expensive. GPS receivers as accessories for PCs are now available at prices of less than $1,000. As sales volumes increase, prices will continue to come down and additional hardware and software features will be added.

GPS receivers are an important component of vehicle navigation systems currently being tested. It is included as a component of the in-vehicle navigation systems and vehicle emergency notification (Mayday) systems being considered as part of the National ITS Architecture being developed. Vehicle location using this technology coupled with a data channel linking a public service vehicle (police, fire, transit, etc.) to the TOC is being evaluated as a component of incident response systems elsewhere in the United States. The ability to locate emergency response vehicles in real time on a status map is a very useful tool in managing and coordinating incident response over a wide area. After some initial operational experience is gained from systems currently in development, the effectiveness and costs can be evaluated for possible use.

Automatic Vehicle Location (AVL): A variation on the GPS strategy is the use of fixed location beacons that can be monitored by a vehicle, such as a bus. Through the use of an on-board computer, monitoring of the vehicle's movement with an electronic odometer, and known information about a route to be followed, the location of the vehicle can be estimated. The location beacon allows the strategy to be refined by providing "check-points" that permit the on-board computer to update and correct its estimates of location.

The periodic transmission of vehicle location to a central computer allows a central dispatcher to track the vehicle. This tracking can be matched to a bus schedule, for example, and alert the driver and the dispatcher if the bus is ahead of or behind schedule. This automated vehicle monitoring can be input to the traffic management system, providing active probes in the vehicle stream, similar to the AVI system discussed above. Although monitoring transit vehicles through an AVL system would be possible in Grand Rapids, it would be of limited benefit-for freeway monitoring due to the lack of transit vehicles using the freeway. When transit vehicles are used as probes, the start/stop nature of transit vehicles must be taken into account when estimating the flow of traffic. The integration of this tracking with voice communications to the bus driver is a very useful tool in locating incidents, and determining their nature and severity.

Detector Comparison Matrix

Table 5-2 illustrates the major features of the most common types of vehicle detectors. This table includes the primary parameter that is most directly measured by the detector and the preferred mounting.

Table 5-2. Major Features of Common Vehicle Detectors

DETECTOR TYPE	PRIMARY DATA	MOUNTING LOCATION	COMMENTS
Loop	Presence	Roadway per lane	Roadway cut installation life approx. 3 yrs.
Piezoelectric	Axle count, Weight	Roadway per lane	Installation involves roadway cut.
Radar (CW)	Speed	Overhead per lane	Poor results at low speeds.
Radar (multi-zone)	Presence	Overhead, Side, Multilane	Some tests show difficult calibration.
Passive IR (non-image)	Presence	Overhead per lane	Few installations.
Passive IR (image)	Presence	Overhead, Side, Multilane	Few installations.
Active IR (non-image)	Presence	Overhead per lane	Few installations,
Acoustic (passive)	Presence	Overhead per lane	Some tests show reliable operation. Few installations.
Ultrasonic (pulsed)	Presence	Overhead per lane	Poor sample rate for high speed flow statistics.
Ultrasonic (CW)	Presence	Overhead per lane	Poor results at low speeds.
Magnetometer or Microloop	Presence	Roadway per lane	Manufacturer claims good results on bridge decks.
Video Image	Tracking	Overhead, Side	40 ft mounting height suggested.
AVI	Travel time, Location	Overhead, Side, Limited Range	Proven benefits for transit fleet management.

Closed Circuit Television (CCTV)

CCTV provides the eyes for the operator at the traffic operations center, and has proven to be one of the most valuable elements of an advanced traffic management system. Operational experience shows that constant monitoring of CCTV images by operators is not effective, as the operator soon becomes "numbed" by the constant repetition of vehicles moving across the screen. The primary role of CCTV is to verify a reported incident or other traffic condition, to evaluate its severity, and determine the appropriate response vehicles and personnel to dispatch to the incident scene.

In addition to its primary role in incident verification and response coordination, CCTV can also be used for other purposes, including:

- Monitoring the operation of critical signalized intersections that are in the vicinity of the CCTV camera. This allows evaluation of signal timing and the related functions of the controller. One agency has reported the instailation of a spare optical fiber to each intersection so that they can install a CCTV camera on an as-needed basis during trouble shooting and problem isolation. This saves them many trips to the site when they are trying to correct intermittent failures.

- Utilizing the CCTV camera to monitor adjacent parallel streets to a freeway to determine current operating conditions. This allows verification that the arterial streets have adequate vehicle capacity to handle added traffic prior to implementing a freeway diversion plan. Monitoring of the operation of the streets during the diversion to insure successful operation is also available.

- Monitoring motorist response and traffic movements on the mainline and entrance and exit ramps. In some cities, CCTV is also used to verify compliance with ramp metering or HOV restrictions, or observance and response to messages posted on a VMS or transmitted on HAR.

CCTV cameras, lenses and typical mounting heights (40 to 50 feet above the roadway surface) allow monitoring of roughly one-half mile each direction from a camera location. This is, of course, restricted by topography, roadway geometry and vegetation. Some installations have mounted CCTV cameras on high-mast poles or towers more than 100 feet above the road. This added height provides a larger area of coverage, if topography and vegetation are favorable.

Specific selection of camera locations is controlled by the desire to monitor high-incident locations and other areas of interest. Ability to view parallel surface streets and ramps should also be considered in site determination. The constraints imposed by access, available locations for cabinets and pole foundations, and communications often limit the optimum selections. Each prospective site must be investigated to establish the camera range and field-of-view for the mounting height and lens combination selected.

The biggest problem to overcome with CCTV is the transmission of the image from the camera location to the control center. Direct video requires a communications channel that is equivalent to more than 1,500 voice grade audio channels. Thus, most efforts in optimizing CCTV systems are directed toward reducing the bandwidth of the CCTV communications channel. These efforts range from not updating the image in real-time (every l/30 sec), to digitally compressing the image, through analyzing the image and transmitting only the moving elements of the image.

The standard for CCTV pictures is a “broadcast” quality, full-motion, real-time image. At present, this is usually implemented by use of a fiber optic communications system, with a separate full bandwidth fiber allocated between each CCTV camera and a multiplexing hub. With tremendous bandwidth available on a fiber optic system, this direct approach is often the least costly and provides the best performance. When this direct approach is not cost effective, alternative solutions must be utilized.

Camera Type

Color images provide the greatest amount of visual information, and are the preferred choice of most traffic operations centers. However, color CCTV cameras rapidly lose their sensitivity under night, or other dim lighting conditions. Black-and-white cameras, on the other hand, are available that will produce usable images even when it is too dark for a person to see. A black-and-white camera is able to produce a usable image with l/10 or less the light level required for a color camera. Some vendors have solved this dilemma by packaging both a color camera and a black-and-white camera in the same housing. This increases the price of the assembly, but the added cost may be acceptable in some locations. Actual field testing should be performed, or the performance of cameras at existing traffic operations centers should be verified before committing to a specific equipment selection. The typical cost of a color camera, with field controller and cabinet, pan/tilt unit, housing and mount, and installation and testing is roughly $20,000.

Pan/Tilt/Zoom/Focus Control

The CCTV camera in the field must be moveable (left and right, and up and down) in order to permit it to monitor the greatest possible area. Similarly, a zoom lens to allow viewing of vehicles at varying distances and associated focus control is required. These functions must be capable of being controlled by all operators who have access to the CCTV images. This functionality is implemented by placing a microcomputer at each CCTV location that receives commands from the traffic operator. This microcomputer turns on and off the appropriate motor in the pan/tilt unit or the motorized lens.

Each CCTV system vendor has its own proprietary system for this type of control. As systems grow and expand over time, control compatibility must be maintained so that the operator is not faced with several different camera control systems. The needs for the control system, both initial and long-term, must be addressed during the system architecture design, considering the growth requirements and future needs.

Digital vs. Analog Transmission

The technology used to date for most long haul, “broadcast quality” CCTV systems has been analog transmission. Within the past five years, significant progress has been made in the development of cost-effective digital transmission equipment. Once video is converted to the appropriate digital format, it can be transmitted long distances over a fiber optic link using a digital protocol such as a Synchronous Optical Network (SONET) communications system with no further conversion and without degradation of image quality. Additionally, digital video switches are smaller and less expensive than analog switches.

Another benefit of digital video is the ability to compress the video image, and thus utilize lower bandwidth on a less expensive data communications channel, which may be used to transport the video to another facility. Typical compression ratios are 40:l. The cost of compression/decompression (codec) equipment is currently about $20,000 per unit, but new products are being discussed which may bring the price down into the $5,000 range. Given normal price/performance curves in the digital electronics industry, this price drop will probably require about 3 years. However, if the price/performance ratio of digital systems does not progress as rapidly as desired, an analog system will provide fully satisfactory results.

Fiber vs. Coaxial Transmission

The use of fiber optics for transmission of video has almost completely replaced the use of coaxial cable, except for very short runs of less than 500 feet. Disadvantages of coaxial cable include requirements for amplification of the transmitted signal every few thousand feet to compensate for signal attenuation and the susceptibility of the cable to induced noise. Fiber optic transceivers are now available with ranges up to five miles for multi-mode fiber, and over 20 miles for single-mode fiber. These transceivers range from less than $300 for short range units to over $2000 for long range devices.

Geographically Distributed Control

An effective and needed strategy in modem incident/traffic management systems is distributing video images to the multiple locations and agencies that can utilize them. This provides for joint, coordinated response to an incident. In addition to the video images, camera selection and pan/tilt/zoom control must also be distributed. Geographic distribution of these control functions may be considered in the basic design of the CCTV system, since adding these capabilities to a simpler system is often difficult and costly.

Video Switch

A key component of the CCTV system is the video switch that allows any CCTV camera to be viewed on any monitor, at any location that has access to the CCTV system. A variety of switch architectures are available, from fully centralized to fully distributed. Each has its own advantages and disadvantages, and associated costs. Most CCTV systems have more cameras than monitors, with typical ratios being in the 3:l to 10:l range.

The cost of analog video switches is a function of the number of switching points, which is the product of the number of camera inputs and monitor outputs. Thus, prices can increase exponentially as the size of the switch grows. For a relatively small switch (30 camera inputs and 10 monitor outputs) the installed cost is about $20,000. Doubling the size of the switch to 60 camera inputs and 20 monitor outputs results in the cost increasing to about $75,000.

Newer digital techniques, similar in concept to a local area network (LAN), are being utilized to transmit and switch video images. With these techniques, the video image is digitized and divided into small segments. These segments (or packets) are then distributed on a very high speed transmission system, and those users who need to view a particular image copy the packets for that image and reassemble the image for viewing. This strategy is commonly used in the telephone industry for switching voice conversations. Since switches of this nature do not increase exponentially in size, they have the potential for being less expensive than analog switches. However, because of the high bandwidth and transmission speeds required, these devices are still more expensive than moderate sized analog switches. With the typical decline in costs for all digital based systems, digital switching of video images is expected to become a cost effective alternative.

In all cases, the cost of video monitors, interconnection to the video transmission system and monitors, operator controls and system integration must be added to the cost of the basic switch.

Large Screen Video

A large video screen (Often 3’ x 4’, or larger) is frequently included in traffic operations centers. The ability to project either an enlarged video image, or an enlarged computer generated graphic can be useful for decision support during incident response or for public relations during tours or demonstrations. Operators in TOC’s with large screens report that they seldom use these enlarged images during normal operations.

Two fundamental technologies are available: video projection, and video wall. Video projection utilizes either a CRT (cathode ray tube) or an LCD (liquid crystal display) system to optically enlarge the image and display it on a screen (using either front or rear projection). Care must be exercised with respect to room lighting since the projected image is easily washed out by typically available light. A video wall provides a large display area that overcomes this problem. The video wall combines a number of moderate sized (21 inch typical) video monitors into an array. This array is often four monitors high and four monitors across. Electronic circuitry divides the original image into smaller parts (for example, sixteen images for a 4 x 4 array) and displays each sub-image on a separate CRT. Current cost for large screen projectors is in the $20,000 range, while video walls are often more than $50,000.

COMMUNICATIONS TECHNOLOGIES

Two primary alternatives are available for system communications commercial circuits, or agency owned circuits. Typical systems use a mix of these alternatives, driven by costs and requirements. Extensive discussions of this topic are provided in literature, in particular the "Communications Handbook for Traffic Control Systems" published by the FHWA in 1993.

Communications technology is rapidly changing, providing faster and higher capacity circuits at lower costs. New wireless options are emerging, spurred by growth in portable computers and personal communications. To take advantage of these changes, the system communications architecture must be flexible and designed around common and commercially supported standards.

Commercially Owned Facilities

The local telephone company, cellular carriers, and other communications service suppliers provide a variety of circuits operating at a wide range of speeds. Initial installation costs and short term monthly costs for low speed data circuits are low, and are thus advantageous for vehicle detection and variable message sign circuits. Maintenance and repair is provided by the commercial service provider, removing the requirement for special training or equipment within an agency. The drawback of this arrangement is the "finger pointing" that often occurs when multiple parties are involved. The primary disadvantages are the long term costs (i.e., recurring monthly billings), and the expense of high speed circuits. Since the monthly costs are considered operational expenses, they must be budgeted from annual operations budgets and are thus often more difficult to obtain than initial capital funds.

Commercial communications circuits are available as either switched (dial-up) or dedicated (private line) facilities. Each of these basic types can be configured as point-to-point (2 parties) or multi-point (three or more parties) circuits. For dial-up service, a multi-point circuit is usually referred to as a "conference call". For dedicated circuits, the term multi-drop circuit is often used interchangeably with multi-point. A further distinction is the transmission technique used: analogor digital. The original telephone network was designed as an analog system for the transmission of voice. The availability of low-cost, high-performance computer circuits has allowed the telephone system to convert much of its transmission and switching equipment to digital technologies, resulting in better quality and performance at reduced cost.

Pricing of commercial circuits typically involves a one-time installation charge, and a recurring monthly charge. Circuits can be obtained on a month-by-month basis, or on various contractual terms ranging from 1 year to 10 years. Month-by-month service provides the most flexibility since service can be terminated when required, but it is the most expensive option. Multi-year contracts provide lower monthly costs, but include penalties for cancellation prior to the end of the contract period.

Dial-up Analog Service

This is the basic voice-grade telephone service provided for residences and businesses. These channels are provided to support voice communications, and are universally available. Currently available modems (modulator/demodulator) provide data transmission speeds in excess of 14.4 Kbps on dial-up phone lines. These units are inexpensive (about $250), and widely available with numerous features and options. They are extensively used on personal computers for data and fax transmission. and well supported by commercially available PC software.

Dial-up telephone service is a useful alternative for occasional, relatively short-term data transmission. The dialing and connect time (15-30 seconds) does not realistically permit data collection or control of devices more frequently than every five minutes. The dial-up telephone network is designed and configured for human calling patterns and call holding periods. allowing the expensive central office equipment to be shared among many subscribers. Use of dial-up circuits for frequent data calls, or for long holding times. or for many hours of use per day, ties up the central office equipment and results in the local telephone company complaining about inappropriate usage.

The other concern with any dial-up configuration is security. The ability of "hackers" to break into computer systems has been widely reported, and cases of inappropriate or unsafe messages being displayed on VMS's through dial-up access have been documented. The use of dial-up/dial-back, encryption, security passwords, and other safeguards reduces the risk for these cases, but at the expense of increased system complexity and additional "hassle" for the personnel who have to support and maintain the system.

Integrated Services Digital Network

The technology for Integrated Services Digital Network (ISDN) was developed by the telephone industry during the early 1980s but has seen a very slow implementation. In the past few years, however, the penetration has increased significantly in many areas. The key benefit claimed for ISDN is the availability of 144 Kbps (divided into two 64 Kbps data channels and one 16 Kbps control channel) of switched digital data over two pairs of wires. Another benefit is the reduced switching/interconnect time, making it feasible to support more field devices on dial-up connections. There are two ISDN user offerings: the Basic Rate Interface (BRI), and the Primary Rate Interface (PRI). Basic rate ISDN is the digital equivalent of dial-up analog service. Primary rate ISDN is the equivalent of T-l service, it provides the user with 23 channels of 64 Kbps data and one control channel operating at 64 Kbps. Interface boards (equivalent to modems) for certain types of computers are coming down in price (into the $1,000-$2000 range) and increasing in availability.

For the current generation of incident traffic management system equipment, utilization of ISDN circuits is probably not feasible due to the lack of interface boards for the equipment. Circuit availability is also a limiting factor. However, the next generation of equipment may well be able to take advantage of ISDN. Since ISDN was developed as a digital service, its error characteristics and operational parameters will result in excellent performance. The current lack of interface boards, and limited availability of ISDN service limits the usefulness for current projects. Furthermore, since ISDN is basically a 'dial-up' service. its use for full-rime channels, as typically used for traffic monitoring applications, may not be effective.

Video devices on the other hand are coming on the market with ISDN compliant interfaces. It may be feasible to utilize this technology to access remote cameras and transmit the video images to the TOC. The bandwidth available on a single BRI circuit is probably not enough for most applications to show traffic motion. Some manufacturers are providing inverse multiplexing capabilities in their equipment that obtains the required bandwidth from the inclusion of additional BRI data channels.

Dedicated Voice Grade Analog Channels

These circuits have been the back-bone of many traffic management and arterial control systems over the past twenty years. Modems to utilize these circuits are included in the design of 170 and NEMA equipment. They can be configured as either point-to-point or multi-point circuits, and can support speeds in excess of 9600 bps with current modem technology. There is a wide range of equipment available for interface to these channels. There are reports of telephone companies changing their tariffs and pricing policies to discourage use of these channels over the long term, in an attempt to move customers to digital channels. The primary advantages of these circuits is their wide-spread availability and their low cost for low speed circuits. Since these channels are designed for voice, they are not optimized for the transmission of data.

Digital Data Channels

The telephone companies offer a range of digital channels running from 2.4 Kbps to 64 Kbps. They are often referred to as DDS (DATAPHONE Digital Service) circuits. These circuits are primarily dedicated circuits. but are occasionally available in a switched configuration. A difficulty with these circuits is that they are usually configured as 'synchronous' data circuits, while most communications for incident/traffic management systems is 'asynchronous'. requiring adapters at each end of the circuit. Since these channels are designed for data transmission, their reliability and operational characteristics are very good. The principle disadvantages are the fundamental 'synchronous' nature of the channels, and the limited availability of the Data/Channel Service Units (DSU/CSU) needed to connect to the circuits.

Digital Carrier

In the mid-1960s, the telephone companies began converting their long-haul trunk circuits from analog technology to digital technology. The basic implementation was the DS-1 (Digital Service 1) channel, operating at 1.544 Mbps. Note that this channel is commonly referred to as a T-l circuit. This T-l circuit is configured to support 24 voice grade channels, each requiring 64 Kbps of digital bandwidth. There is a hierarchy of faster digital circuits, each built upon various combinations of T-l circuits. A typical combination is DS-3 (T-3) at 43.232 Mbps, or 672 voice grade channels. The emerging Synchronous Optical Network (SONET) standard builds upon DS-3, and is defined in various combinations as high as OC-48 (Optical Carrier 48). which operates at 2,488 Mbps, or the equivalent of 32,256 voice grade channels.

Within the past few years, T-l service is becoming readily available to end users, driven by the demand for higher speed communications channels to link computers and local area networks together. The primary interest in T-l for traffic/incident management systems is digital transmission of video signals. T-l provides a reasonable option to agency owned fiber optic cable for a few circuits, and limited period of time. but quickly becomes quite expensive if large numbers of circuits are involved.

Cellular Telephone Service

Cellular telephones have rapidly expanded their market penetration over the past five years, pushed by the convenience and declining prices. The cellular telephone network now covers over 93 percent of the United States population. Off-the-shelf cellular modems permit the transmission of data over the cellular network. Note however, that cellular modems utilize different techniques for error correction and circuit initialization, and thus are often not compatible with landline modems. The use of cellular telephones by field personnel has simplified many maintenance and incident response procedures.

The ready availability of service and capability to locate equipment anywhere within the coverage area provides a high degree of flexibility, especially for temporary installations, and portable or mobile equipment. Cellular equipment eliminates the need to connect to a telephone company service point. This capability of establishing a circuit on an as needed basis may prove cost effective for infrequent communications.

The primary disadvantage of cellular service is its cost. Each cellular "telephone" incurs a monthly service charge ranging from $15 to $45 per month, and a per-minute "airtime" charge ranging from $0.10 to $0.50 per minute. Due to competition, increasing numbers of users and the resulting additional volume, prices are falling. These price decreases are being driven by reduced unit cost reductions and "innovative" service plans. However, even if costs were as low as 10 cents per minute, airtime costs $144 per day, making full-time cellular communications prohibitively expensive. Since the existing cellular network utilizes analog transmission, it is somewhat noisy and thus limits the speed of data transmission. However, the network may be moving toward digital transmission. which would obviously increase transmission speeds. Some systems are now offering Cellular Digital Packet Data (CDPD) which is the first step in developing digital cellular communications.

Packet Radio

Packet radio is a wireless technique that is designed specifically for the transmission of data. Commercial suppliers utilize radio base stations to communicate with multiple field transceivers via time synchronized bursts, or packets, of data. Since many field transceivers share the same frequency pair for transmitting and receiving data, a cooperation strategy (or communications protocol) is utilized to coordinate this sharing. Because of this sharing, there can be delays of several seconds in delivering a packet. The pricing structure of packet radio is based upon amount of data transmitted. measured- either in bytes or packets. This pricing structure, and the basic architecture of packet radio, is most effective when transmitting short messages, and not large quantities of data. Typical prices are $0.03 per 100 bytes transmitted, which results in a cost of about $5.00 per hour for real-time communications with a traffic monitoring processor. This cost is prohibitive for continuous communications, but may be attractive for occasional use to some remote VMS and weather station controllers that would have been reached by cellular telephone. Considerable development may be required to convert the remote device and central processor to communicate in packet network protocol.

Satellite Communications

Satellite communications services have been available for many years, and have proven cost effective for long-distance point-to-point circuits and for wide-area broadcast applications. However, for "local" applications (distances less than a few hundred miles), the costs of ground stations and satellite transponder rentals are prohibitive for traffic management applications. A typical monthly cost for a 56 Kbps circuit is $10,000 - however, this is essentially independent of circuit distance, with a 200 or 2000 mile circuit costing the same.

The one case where satellite communications has proven useful for traffic management is incident response in rural areas. The ability to deploy an incident response vehicle, with voice, data and limited-motion video communications to a central control facility, has proven effective in field trials. The flexibility of this approach is a significant benefit, but the cost needs to be weighed against other communications channels.

Agency Owned Facilities

In an effort to reduce monthly operating costs, and to provide the communications bandwidth needed for large numbers of video cameras, many agencies install their own communications facilities. For cable based land line systems, the cable and electronics are moderately priced; but the cost of trenching, installing conduits and ducts. backfilling and patching is significant. Depending upon construction conditions, conduit installation costs can range from $20/foot to $40/foot. This translates to $100,000-$200,000 per mile. These costs will be even higher if structures need to be crossed, roads to be bored under, etc.. The cable, installation. splicing, and electronics termination equipment will cost from $5/foot to $15/foot, depending upon the specifics of the installation.

However, conduit can be installed at minimal cost during highway construction and re-construction activities. It seems reasonable to provide for future needs by placing conduit during any major roadway construction, provided that a means of record keeping can be utilized to locate this conduit when it **is** needed. Innerduct can be added at a later time if necessary. To save in trenching costs, conduit may be stacked on top of each other (for example, the New Jersey DOT stacks two 4" rigid non-metallic conduit one on top of the other in a 6 inch wide trench) or buried side by side (Washington State DOT has installed two conduits buried side by side in a 1 foot - 7 inch wide trench, and four conduits in the same size trench, side by side and stacked).

Several agencies also include innerduct in their conduit. This provides extra non-obtrusive space for additional cable to be pulled through the conduit. There are different types of conduit with innerducts. Fiberglass conduit has four chambers molded right into the conduit. With the standard rigid metallic and non-metallic conduit, innerduct must be pulled through the conduit to provide separate raceways for cable.

Twisted Pair Cable

Twisted pair cable has been the backbone of "the last mile" in communications systems for decades. It provides a simple, straightforward and low cost method for the short haul circuits from the termination of high capacity back-bone (long haul) circuits to the individual Vehicle Detector cabinets or Variable Message Signs. Twisted pair works well for speeds up to 28,800 bps for distances of several miles. However, if the system connects numerous nodes, a slower baud rate (approx. 1,200) is suggested for faster synchronization. Twisted pair cable is usually installed in combination with a fiber optic long-haul system to interconnect the field equipment to the communications hub.

Coaxial Cable

Coaxial cable was previously used for transmission of video images from CCTV cameras into a control center. Due to the need for active amplification every l/2 mile, image degradation over long cables, and maintenance problems, coaxial cable is no longer recommended for this application.

Micro wave

Point-to-point microwave is an attractive alternative for initial, or periodic, transmission of video images from CCTV cameras. Microwave can be utilized for those cases where it is neither technically feasible nor cost effective to install conduit and fiber optic cable. Depending on performance, a microwave system (including transmitter and receiver, usually with a reverse direction control channel) for video transmission costs from $20,000 to $40,000. This equipment is very useful in the initial stages of system implementation, such as before a fiber optic system can be installed. As the fiber optic system is installed. the microwave equipment can then be re-used to extend CCTV coverage beyond the end of the fiber optic network. A key limitation of microwave is the requirement for line-of-sight. Another problem with microwave is its degradation under adverse weather conditions. A microwave installation must receive a license on a site by site basis from the FCC.

Wireless Video

A recent development in video transmission equipment is wireless video. This equipment transmits full motion video over a radio circuit in a manner similar to that used by microwave but without the stringent installation requirements. Wireless video does require line-of-sight, but the antennas are much less sensitive to alignment. The wireless video also does not require the licenses needed by microwave since the equipment is class licensed by the manufacturer.

Spread Spectrum Radio

Spread spectrum radio transmission was developed nearly 50 years ago by the military as a security measure. These techniques were commercialized starting in 1985 when the FCC assigned frequency bands to spread spectrum radio. The technology spreads the signal bandwidth over a wide range of frequencies at the transmitter. The receiver knows the technique (or coding) utilized, and it thus able to recover the transmitted signal and reconstruct the original message.

Because each communications circuit within a given band utilizes a different coding technique, multiple. simultaneous circuits can co-exist. Spread spectrum generally requires line-of-sight, limiting its range to about 6 miles. The signal is attenuated by vegetation, so a site survey is recommended before committing to this technology. Field equipment can be placed anywhere within the range of a base station, thus very flexible installations can be developed. The basic technique of spreading the transmitted signal over multiple frequencies results in high noise immunity. The FCC has assigned the 902-928 MHz band for which no facilities license is required. However. spread spectrum equipment operating in this band cannot interfere with licensed equipment, and must accept interference from licensed services.

For traffic management applications, there is significant potential for spread spectrum radio. The work that is currently under way to evaluate spread spectrum for the next generation of digital cellular telephones may result in a wide spread application of the technology. If this occurs, there will be an increased availability of equipment and resultant price reductions. However, the technological complications will result in increased personnel training and specialization, and more sophisticated equipment.

Fiber Optic Cable

Fiber optic cable is being installed in virtually all new communications systems used for incident/traffic management. Fiber optic cables provide very high data rates (2.5 Gbps) over long distances (over 25 miles) without amplification. Other advantages are the small cable diameters (a 0.5” cable can contain 72 fibers), immunity from electrical interference, and avoidance of ground loop and lightning strike problems encountered with metallic conductors.

Fiber optic cable is commonly manufactured with two internal structures: those fibers that support single mode transmission and those that support multi mode transmission. Single mode fibers are used for long-haul circuits that are longer than a few miles, but require more expensive transmission and receiving equipment to take advantage of its higher performance characteristics. Multi mode fibers are typically used to transmit video images a short distance from the CCTV camera to a communications hub that is at most a few miles away, where the images are combined, or multiplexed, onto a long haul single mode fiber for transmission to the control center. Multi mode fiber utilizes lower cost transmission and receiving equipment, but has a limited transmission range.

Many private telephone and cable television companies, such as TCI, are upgrading their systems to fiber optics. This may allow for a public/private partnership for the installation of the fiber optic system in order to reduce the installation and maintenance costs.

Fiber Optic System Architecture

Fiber optic communications systems were initially developed in the 1960s by the telephone companies for long haul transmission of voice and data. The technology has undergone successive refinement over the past quarter-century, and is today the technology of choice for essentially all new communications systems. Early implementations of fiber optic systems replicated the existing systems that were based on twisted pair, coaxial cable and microwave channels, specifically implementing digital carrier systems at DS-I (1.544 Mbps) and DS-3 (43.232 Mbps) transmission rates.

Within the past 10 years, a new standard termed Synchronous Optical Network (SONET) has been developed. The SONET standard is based upon multiples of 51.84 Mbps, which is known as an Optical Carrier I (OC-I) channel. An OC-I channel carries a DS-3 data stream, plus additional control and status information. SONET systems typically are installed with OC-3 (155.52 Mbps), or OC-12 (622.08 Mbps) capacity, with some systems implementing OC-48 (2488.32 Mbps). Faster data streams are being planned.

A key design concept of SONET is redundancy. This redundancy is achieved by the use of dual counter-rotating ring circuits. These rings provide for automatic rerouting of traffic onto the secondary ring, in the event of a failure in the primary ring. Since the secondary ring transmits data in the opposite direction from the primary ring, a cable break at one location does not result in a system failure. This re-routing capability is referred to as a self-healing ring. The switch-over from the primary to secondary ring occurs rapidly enough that most data communications can recover without data loss, however, real-time traffic such as voice or video may incur a momentary loss of communications. Restoration of full system functionality requires field repair of the broken cable. Equipment failures are also contained by the inclusion of redundant components at all key locations. This redundancy is included in the basic design of the SONET system.

While alternative configurations may be considered, SONET is the preferred choice of all new communications systems. The use of SONET by the telephone companies and long-distance carriers has resulted in a wide range of manufacturers and vendors of equipment. The resulting competition has generated a wide range of features and capabilities, and very attractive benefit-cost ratios. Other alternatives do not have the range of options and features, and typically are more expensive when compared to SONET on a functionality basis.

The advantage of SONET is also its greatest drawback: the very wide bandwidth that is supported. This communications capacity results in higher costs when compared to the lower bandwidth solutions, but extending the lower end solutions to SONET capabilities ultimately requires a higher system cost. The other limitation of the higher bandwidth is the impact of a system failure, in that it impacts more field devices and communications channels. However, the self-healing capability and designed-in redundancy of SONET typically results in a more reliable overall system.

The design of a SONET system utilizes four single mode fibers on each link, preferably with two separate routings, using 1310 nm or 1550 nm for transmission. Interconnection of field devices to the SONET backbone requires the use of a "communications hub". A hub serves to interconnect low speed (1200 bps to 9600 bps) data streams from individual 170 controllers, VMSs, etc. to the much higher data rates of the SONET backbone. This interconnection is performed by devices knows as multiplexors/demultiplexors. Data originating at several field devices is combined together in a "time-slice" format for transmission to the central facility. This combination makes best use of the capacity of the SONET system. In the reverse direction, the data coming from the central facility is extracted from, or demultiplexed, from the combined data stream and routed to individual field devices. An equivalent set of multiplexors/demultiplexors exists at the central facility to perform the same functions of combining and separating data.

Since voice can be represented in a digital format, the SONET system can also be used for voice communications. Digital transmission of voice is extensively used by all the telephone companies and long-distance carriers, and has been the driving force behind the development of digital carrier and SONET technologies. Highly cost-effective and very reliable systems are thus available from the telephone company equipment suppliers. Agencies often utilize this voice capability of a SONET system to impiement PBX-to-PBX links between various locations, and to bypass the telephone companies to reduce their long distance charges.

Fiber Optic Network Configurations

There are three basic network configurations, or topologies, that are used to design fiber optic systems: Star, Bus, and Ring.

Star Configuration: In a star configuration, separate fiber optic trunks are used to connect the communications hubs to the central facility. At each hub, connections are made to the field devices through a local distribution network which can consist of several different types of media, such as fiber optic cables, twisted pair, or radio based communications. The data to and from the central facility is multiplexed and demultiplexed at the communications hub.

This type of configuration has a disadvantage in that separate "home runs" are required from each hub to the central facility, and that it is typically not configured with redundant, automatic switch-over, fibers or equipment. However, this is a proven system and has been successfully used in many traffic management systems.

Bus Configuration: In a bus configuration each communications unit, which may be a device located at a node or communications hub, or a field device such as a 170 controller, is connected to a fiber optic link or series of fibers carrying data in two directions, i.e., full duplex. Every device connected on the bus is assigned a channel and an address. Each device is accessed by polling it on its assigned channel, using the specified address, to retrieve data in the device and to send it control information. This bus configuration is commonly used in local area networks (LANs) used to link together personal computers.

The advantage of this configuration is the use of a single communications facility reaching from the central location to each field device. However, low cost fiber optic modems that are directly compatible with 170 controllers, VMSs, and related equipment are not readily available. This technology has not been utilized in operational traffic management systems, and thus there is very limited experience.

Ring Configuration: Ring configurations can be implemented as either a single ring, or as a dual (redundant) ring. Most ring configurations being installed today utilize a dual ring to take advantage of automatic reconfiguration, or self-healing capability of the system. This fault-tolerant approach significantly increases system reliability.

The operational advantages of self-healing rings are clear. Because this configuration is being widely implemented and utilized, a full range of equipment at competitive prices is readily available. The disadvantages are the requirement for additional fibers, and redundant equipment at the communications nodes. However, the incremental costs of additional fibers within the same cable is very small (approximately $150 per fiber per kilometer). Similarly, the incremental costs of redundant equipment, when compared to the life-cycle cost of system failures is again quite small.

Star-Ring Configuration: A combination of the star and ring configurations is recommended in the Grand Rapids area due to the geometric configuration of the roadways, and the redundancy provided by such a configuration.

TRAVELER INTERFACE TECHNOLOGIES

Variable Message Signs

Variable Message Signs (VMS), both fixed and portable, are widely used to provide motorist information during an incident. The ability to quickly alert motorists of a problem ahead, and provide for diversion to an alternate route, is a successful strategy for minimizing the impact of an incident.

A VMS consists of a matrix of dots, each of which can be individually controlled. The minimum group of dots for a single character is five dots horizontally and seven dots vertically. Larger “character cells” are often implemented for improved character resolution, the use of lower case letters, and “double stroke” characters. Since individual characters on a VMS are composed of discrete dots, the “sharpness” of a character is controlled by the number of dots per character. The tradeoff is cost, with cost of the sign being proportional to the number of dots on its surface. The human eye fuses together the adjacent dots in the character pattern, and recognizes the character as a whole. In general. the legibility of 5 by 7 character cell VMS’s is very acceptable, especially if only upper case letters are used, which is typical for roadway applications. When lower case is required. or other effects are needed, larger character cells, and proportionally more expensive signs, are necessary.

If the VMS is intended for text messages only, adjacent "character cells" can be separated by a blank space to minimize the cost of the sign. An alternative approach is the "continuous matrix" sign, in which the separating blank space is deleted, resulting in all locations on the surface of the sign being controllable. This permits moving text, "exploding" and "collapsing" images, roller blind, horizontal shutter, and other types of special effects to be implemented. These special effects are more commonly used in commercial displays than in roadway applications. Use of a proportional font for improved readability or graphics is a common use of continuous matrix signs on a roadway.

Various display philosophies are in use by different agencies. Some feel that a VMS should only be used when necessary to display instructions or information about roadway conditions, feeling that if routine messages are displayed, the driver's awareness of the sign becomes numbed. Other agencies display a routine or safety message on the signs to confirm operability, while some agencies use their signs to advertise events. Because a VMS can display a wide variety of characters in each character cell, dynamic messages can be created by manipulating the timing of the display of individual characters; or groups of characters. Simple effects that are quite effective for roadways include blinking text, moving arrows, and the cyclic display of a sequence of messages with delays between them. An example of the latter is displaying a repeating series of safety messages, such as "BUCKLE UP", "DRIVE 55 FOR SAFETY", and "USE YOUR SEAT BELT". Message complexity, information acceptance rate, and driver attention span all must be considered when utilizing these features on high speed roads.

Two fundamental technologies, light reflectance and light emission, are used to form the individual dots that create the letters of the message.

Light Reflective Signs

Light reflecting VMS's consist typically of a matrix of mechanically changed dots. The individual dot can be a flat disk that is black on one side, and colored on the other, or a ball or cube that has color on one half, or a split flap that exposes a colored surface when opened. Other implementations consist of a multi-part flap that some vendors have utilized to implement a "white" character for daytime usage, and a "fluorescent color" character for improved visibility at night. This technique has been extended by one vendor to allow display of six different colors for each pixel. A variety of techniques have been used to improve the visibility of these signs, including internal illumination and retro-reflective surfaces. Because the dots are mechanically moved. a finite amount of time is required to change the message displayed on the sign. Different vendor's implementations result in a range of timing characteristics. On the slow end of the spectrum, rates of 30 characters per second are typical. At this speed, a sign with three rows of twenty-two characters per row will require over two seconds to change its message. Faster character write rates are available, some capable changing the entire message in parallel, but tradeoffs of power consumption, dot inertia, overshoot, and flutter all enter into the dynamics of the implementation.

To provide stability during periods of power outage so that dots do not randomly change position and display "garbage" on the sign face, and to reduce power consumption, some method of latching the dots into a fixed position is normally used. A common technique is magnetic, where a small fixed magnet is attached to the shaft on which the dot rotates. The dot is changed from its "dark" state to its "bright" state with a pulse of an electromagnet, thereafter remaining stable with no power input required. This has the advantage that a message that was displayed prior to a power failure will remain on the sign face.

These signs have a proven field track record, with a generally high reliability rate. Individual dots are rated in the range of 100 million operations. However. it is not uncommon to find individual dots stuck, either "dark" or "bright", as a sign ages. The signs are fabricated for easy repair, with each character cell being quickly replaceable, and individual dots being repairable. The technology is easily scaleable, with character sizes ranging from 2" to 18" in height. A wide range of colors can be used on the "bright" side of the dot, with white or yellow being most common, but green, red, orange. gold, and others are becoming available. Because of the mechanical nature of this technology, a weatherproof enclosure is required. Cost of these signs is in the medium to expensive range, depending upon size, mounting, enclosures, and various options. For many agencies, these signs have been the "mainstay" of their VMS implementations.

By mechanically rotating the disk, ball, or flap with different colors on the surfaces, the dots on the surface of the sign form letters. The key advantage of this type of sign is the maturity of technology, and the long experience of their usage. Another advantage is the continued operation of the sign during a power outage, since the dots are bi-stable -- requiring power to change their state, but not to maintain them in a particular state. The disadvantages include limited visibility under some lighting conditions, fading of color contrast over time, and mechanical failures resulting in a "stuck dot".

Costs of these signs is a direct function of the number of characters on the sign face, and the attention to detail and quality by the manufacturer. Since this type of sign is electro-mechanical, operational experience and product refinement based on many years of development have an impact on long term reliability. Large signs (3 rows by 20 characters/row) range in cost from $50,000 to $90,000, including installation and commissioning. Small signs (3 rows by 8 characters/row) cost $25,000 to $50,000. Cost of the support structure (sign bridge, attachment to overpass, or roadside poles) is in addition to the basic sign cost.

A related type of sign is the changeable seven segment numerical display. This technology is useful for the display of variable speed limits. A sign may be fabricated in the form prescribed by MUTCD for a speed limit signal with the numerical digits formed by remotely controlled displays. This technique produces an easily recognized, variable speed limit that is less costly than a full VMS.

Another related sign is the rotating drum sign, where several faces of a rotating drum (or several drums) can be used to display one of several messages. These signs can be configured with the same size, shape, and letter fonts as traditional static signs. Further advantages are their lower cost when compared to a "dot matrix" sign, and mechanical simplicity resulting in higher reliability, Their prime disadvantage is the limited number of messages that can be displayed on a single sign. The drum sign has applications where a fixed message (such as LANE OPEN/LANE CLOSED) has to be displayed for portions of a day. Their use for incident response is limited.

Light Emitting Signs

The use of an active light source at each dot (or pixel) of a VMS produces a light emitting sign. The original light emitting sign is the incandescent bulb matrix. This type of sign provides good visibility, and is currently used in commercial applications. However, it has fallen into disfavor for roadway applications due to the low reliability and high maintenance costs from bulbs burning out. Another major problem is heat as a result of the high bulb wattage, and the resultant power consumption. Some agencies in warm climates have found that they have to limit the number of bulbs that are simultaneously ON due to heat rise in the sign enclosure. In general, these signs are not favored because of these limitations.

Current technology developments utilizing “solid state” lamps over the past several years have produced signs with high brightness, simple control, and long life. The light source in these signs is the light emitting diode (LED). Until recently, the brightness of the LED has not been fully adequate for bright daylight conditions. In particular, the “amber” LED. which is preferred for roadway usage, has been difficult to manufacture with the desired characteristics. Early LED’s suffered from variability in light output between “identical” LED’s, and aging effects which reduced brightness (often non-uniformly) over time. However, about three years ago these problems appear to have been solved, and the LED sign is finding acceptance in the field with many major manufacturers fabricating these signs.

A typical implementation utilizes a group of LED’s (on the order of 15) to form each individual pixel. This increases the brightness of each pixel, and averages any small differences between adjacent LED’s. These signs have a very fast turn on and turn off time, removing the problems noted above with the rotating disk type signs. Because of the physics of the semiconductor junction and wavelength of emitted photons, LED’s have a limited range of colors. Red is the most common color, but yellow is preferred for most roadway signing applications. Green is also commonly available. Combinations of different colored LED’s are being used to implement “colored” signs. The small size of the LED, coupled with computer type integrated circuits, can produce displays with large numbers of individually controllable dots for special effect applications. The long life of the LED, combined with the inherent simplicity of the design concept, should result in very good reliability. Actual field experience, as these signs are deployed in large numbers, will have to be gathered to verify this expectation. Cost of these signs is moderately expensive, but that should change as their usage increases.

Enhanced visibility is the key advantage of light emitting signs. The ability to mix various color light sources to produce differently colored messages is also useful. The biggest disadvantage of these signs is their requirement for continuous power, making them non-operable during power failures. If power failures are common, and the sign is critical to continued operations, some sort of back-up power is required.

LED’s have had some problems due to loss of light output intensity due to the aging of the light emitting active elements. Intensity reductions on the order of 50% have been observed after 30,000 hours of operation. A side-effect of this problem has been brightness differentials as a result of differing power-on times. This results in variations between different dots on the sign. Newer generations of LED’s appear to have solved these problems, with preliminary reports indicating either no intensity loss, or even a slight gain. This is based on initial testing, with long term field results not yet available. Another benefit of these newer LED’s is their increased intensity, allowing a sign to be fabricated with fewer LED’s per pixel (resulting in a lower fabrication cost), or a brighter sign with the same number of LED’s, or the ability to operate the LED’s at lower power (prolonging their life and reducing the aging effects).

Costs of LED signs is controlled by the size of the sign (number of characters on the sign face), the quality and reliability focus of the manufacturer, and the type of LED used. The newer, high-output amber LED’s are more expensive than older devices because of limited manufacturing yield and the need for the supplier to recover development costs. As with all semiconductor devices, component prices will decline fairly rapidly - especially as sales volumes increase. Large signs (3 rows by 20 characters/row) range in cost from $60,000 to $130,000, including installation and commissioning. Small signs (3 rows by 8 characters/row) cost $40,000 to $60,000. Cost of the support structure (sign bridge attachment to overpass, or roadside poles) is in addition to the basic sign cost.

Hybrid Technology Signs

The combination of a rotating disk or shutter in front of a light source produces a hybrid of mechanical motion and light emission. If the rotating disk is colored on one side, the light source "enhances" the message on the sign, providing additional visibility and "punch" for longer distance viewing. Some vendors consider this an enhancement of the basic rotating disk/shutter sign, while others explain their product as a totally different technology.

The LED is often used as the light source, with the LED being mounted behind the disk, and the disk serving as a shutter to permit the LED to be seen when the disk in the "bright" position, and masking the LED when the disk is in the "dark" position. One implementation mounts the LED off center, with a hole through the disk. When the "bright" side of the disk is visible, the hole is positioned over the LED. When the disk is rotated so that the "dark" side is exposed, the hole and the LED no longer coincide, and the LED is masked. Different vendors implement this same basic idea with a range of schemes, all effectively performing the same task.

A variation of this approach utilizes digital control technology that is connected to the circuit that controls the disk, and turns off the LED at each pixel when the "dark" side of the disk is exposed. This technique requires a location within each pixel that is constantly visible, and works well with circular dots where the LED's can be located in a "comer" of the pixel. However, with split flap pixels that are square or rectangular in shape, the locations for mounting the LED's are limited.

The approach of combining a light source with a light reflecting sign is an effective manner for increasing the visibility of the basic VMS, producing a good combination of daytime and nighttime usage. The prime reliability concerns are those of the basic sign. Cost is greater than that of the basic sign, and the performance enhancement must be considered within the constraints of the project.

A matrix of shuttered pixels, with each pixel containing a fiber optic bundle that is illuminated by a high intensity light source is another combination used by some vendors. The concept utilized with this design is that of a light source for several characters (on the order of three or more), and bundles of optical fibers to "pipe" the light to each individual dot on the sign face. One configuration utilizes a rotating disk as the shutter. In another configuration, the shutter is assembled with its rotational shaft perpendicular to the sign face. This shutter functions in a manner similar to that of a camera: alternately blocking or uncovering the light source. The mechanical orientation of the shutter, and its motion, seem to result in enhanced reliability.

The light source is a high intensity light bulb, similar to that used in a slide projector. The brightness of each individual dot is several times brighter than that obtainable with the hybrid LED sign. A useful design "trick" is to utilize two separate bulbs for each fiber bundle, with an automatic switch over circuit when a bulb fails. Monitoring the current flow of the small number of bulbs involved in this design is convenient, resulting in the ability to report a bulb failure to the central control station. The second bulb can also be used to produce an "over-bright" condition for poor visibility conditions, such as fog. Another convenient feature utilizes a motor driven colored filter between the bulb and the fiber optic bundle to produce different colored characters on the sign face.

This type of sign has carried a higher price tag, making it the "cadillac" of VMS applications. The prime selling feature of these signs has been their brightness and resulting high visibility. Some vendors emphasize the reliability of their signs, which may be more a result of high quality manufacturing and engineering, than the fundamental technology. Competition, other market forces, manufacturing efficiencies, and related factors may eventually push the price down to being more competitive with other technologies. As more of these signs are installed and field experience gained, their relative merits will be more sharply focused.

The combination of devices (light source and mechanical shutters) used to create a hybrid sign increases the cost about 20% over either light reflective, or a light emitting sign. However, the increased visibility is a key benefit that is often required.

The cost of hybrid signs is also dependent upon the size of the sign (number of characters on the sign face), and the approach taken by the manufacturer. The "flip-disk" signs, to which LED's or fiber-optic light sources are added as an enhancement cost 15% to 20% more than the basic sign. Thus, for a large sign (3 rows by 20 characters), the cost will be in the $60,000 to $105,000 range. And a small sign (3 rows by 8 characters) will cost $30,000 to $60,000. The fiber optic sign that utilizes shuttered pixels is primarily available in a 3 row by 18 character configuration, and costs about $135,000, including installation and commissioning. Cost of the support structure (sign bridge, attachment to overpasses or roadside poles) is in addition to the basic sign cost.

VMS Control Systems

As the number of individually controllable elements on the sign face increases, the complexity of the control requirements increases. For all but the simplest rotating drum signs with just a few messages, some sort of computer based control is required. The manufacturers have selected a variety of microcomputers to meet this need. A few manufacturers have selected the Model 170 intersection controller as the microcomputer, which has the advantage of utilizing a standard item of hardware that is familiar to highway agencies. In other cases, the vendor has developed a special purpose microcomputer for controlling the specific sign they manufacture. In all cases though, a unique software package has been developed for each implementation.

Similarly, the command set used for communication between these signs and a control location is unique to each vendor's system. This command set is called the "communications protocol".

For an agency getting started with VMS's, a fully packaged system from a single supplier is simpler because the vendor can be assigned total responsibility for the system. But the "proprietary" nature of each vendor's implementation (because standards have not yet been defined) creates difficulties when trying to integrate equipment from several vendors into an overall system. An agency can easily get "locked into" a single supplier, when there are superior or more cost-effective products available. Or the agency can suffer from poor support, or a product being "orphaned" when a newer model is introduced or a company is bought out.

In any application of VMS's where more than a "few" different messages are to be displayed, some form of central control and operator interface is required. The "central" control computer supplied by the vendor for remote access to and monitoring of the signs is usually a PC, but often with vendor specific hardware enhancements such as unique serial communications boards. The software that runs on the PC is unique to each manufacturer's implementation, and ranges from "convenient" to "obtuse" in its user interface. Prices for the central system range from little more than the cost of the PC itself, to many times that, depending upon the features, the total system size, and the vendor's perception of the value of the central control system. The complexity of this software must not be underestimated. There are a great many features, interdependencies. database management issues, and operating subtleties to be handled, all of which contribute to the implementation difficulty and resultant cost.

The challenges associated with the control system can be addressed by carefully understanding the operational needs of the system, considering the growth requirements and future needs. In all cases. the vendor must be required to supply full documentation of all system components. The details of the communications protocol are especially important, so that existing signs can be integrated into a larger system when the agency's needs evolve. Another option that will be available in the near future is the specification of the National Transportation Communication/ITS Protocol (NTCIP). This protocol is currently under development by NEMA/FHWA for NEMA/170 controllers, and variable message signs. A demonstration of the draft protocol was held at the TRB meeting in Washington, D.C. in January 1996. Selection of a VMS on the basis of ease of integration into a future larger system will usually be beneficial as the overall scope of this type of traffic information system increases.

VMS Communications

The connection between a VMS and the central processor can be provided by a standard serial data communications link, Data requirements for signs are usually small. VMS systems are often implemented with a predetermined library of messages. An operator usually needs only to select a pre-composed message. resulting in a very small communication load. If a completely new message is typed in by an operator. the communication load is only slightly higher. A complex message with graphics will require a larger amount of data to communicate the display to the sign. The communication link to a VMS will not generally need to operate above 1200 bps. This data rate will allow roughly 120 characters per second to be transmitted.

When a secure "closed" communications system is required to prevent unauthorized access to VMS control capability, an owned or leased communication link is necessary. Although the public switched telephone network is an "open" system, security measures can be added. Security measures could include the use of encryption devices and/or call-back security. Encryption involves the transmission of messages in a code that cannot be easily reproduced with a personal computer. Call-back security involves the placement of a call to the VMS and entry of an identification code. The VMS then places a call back to the control point before allowing access to changes in the sign message.

Highway Advisory Radio

Highway advisory radio (HAR) is widely used to provide motorist information to travelers in a limited geographic area. Non-commercial information services include construction and traffic congestion information, possible alternate routes, traveler advisories, parking information at major destinations safety information, availability of lodging, rest stops and local points of interest. AM broadcast-band, low power level equipment has been used to provide this information on two frequencies, 530 KHz and 16 IO KHz. Presently, the standard broadcast frequencies between 530 KHz and 1700 KHz are available, in IO KHz increments, provided there is no interference with existing stations. The transmitters signal must also be low pass filtered in the audio range, to about 4 KHz resulting in a voice quality much like telephone transmission (between 3 KHz and 20 KHz the filter must attenuate at 60 log (f/3)dB where f is the audio frequency in KHz). The HAR transmitter consists of a device to record and playback messages, a radio transmitter, and an antenna. There are three different configurations used for HAR, vertical antenna, "leaky cable", and micro-transmitter. Regulations governing the operation of HAR systems are defined by the FCC rules in Part 90.242.

Vertical Antenna

Probably the most commonly used HAR system utilizes a vertical antenna. This type of HAR is termed a Traveler Information System (TIS) and must be appropriately licensed. A single vertical antenna produces an ornni-directional (circular) radiation pattern that diminishes uniformly as the square of the distance from the antenna, provided there are no geographical obstructions.

- FCC regulations for vertical antenna HAR/TIS stations include the following requirements:
- A separation of at least 15 kilometers from the 0.5 milli-volt/meter day-time contour of any AM broadcast station operating on the same frequency.
- A separation of at least 130 km from the 0.5 milli-volt/meter daytime contour of any AM broadcast station operating on the same frequency.
- The height of the antenna must not exceed 15 meters above ground level.
- The RF output of the transmitter must not exceed 10 watts.
- minimum distance of 15 kilometers must be maintained from any other Vertical Antenna HAR/ITS station.
- minimum distance of 7.5 kilometers from a "leaky cable" antenna HAR/TIS at the same frequency.
- A frequency stability of $\pm$20 Hz must be maintained.

Signal field strength of antenna emission at the operating frequency must not exceed 2.0 milli-volts/meter at a distance of 1.5 kilometers from the HAR antenna.

"Leaky Cable" Antenna

A specially designed lightly shielded coaxial cable is used to provide the antenna for this type of HAR/TIS transmitter. The signal transmitted from this arrangement is strong near the antenna, but dissipates rapidly when the distance from the antenna increases. Compared to a vertical antenna system, much more control of the emission field strength is available. There is less chance of interference with other radio services. Multiple HAR/TIS systems could be operated along a roadway with different messages for traffic in each direction.

FCC regulations for a "leaky cable" antenna HAR/TIS stations include the following requirements.

- A separation of at least 15 kilometers from the 0.5 milli-volt/meter daytime contour of any AM broadcast station operating on an adjacent frequency.
- A separation of at least 130 kilometers from the 0.5 milli-volt/meter daytime contour of any AM broadcast station operating on the same frequency.
- The maximum length of the cable antenna must not exceed 3 kilometers.

- The RF output of the transmitter must not exceed 50 watts.
- A minimum distance of 0.5 kilometers must be maintained from any other HAR/TIS "leaky cable" station.
- A minimum distance of 7.5 kilometers from a vertical antenna HAR/TIS at the same frequency,
- A frequency stability of 20 Hz must be maintained.
- Signal field strength of cable antenna emission at the operating frequency must not exceed 2.0 milli-volts/meter at a distance of 60 meters from any part of the station.

Micro- Transmitter

Very low power HAR transmission is permitted by Part 15 of the FCC regulations without requirements for a license. The area covered by a micro-transmitter is usually defined by a radius of 0.15 to 0.4 kilometers although some manufacturers claim twice as much. Part 15 of the FCC code includes the following requirements:

- The lead length of antenna and ground may not exceed 10 feet.
- Any standard AM frequency between 530 KHz and 1705 KHz may be used.
- The RF output of the transmitter must not exceed 100 milliwatts.

Message Record/Playback

TIS messages to be broadcast on a HAR are usually recorded on an audio tape recorder and more recently in digital memory. Digital memory is preferred since it uses no moving parts, and thus does not require periodic cleaning or maintenance. Some devices offer features including:

- Message capacity of nearly half an hour.
- The ability to retain messages during power failures.
- The ability to provide concentration of various stored message sequences in any order to form the broadcast message.
- A double buffer to allow playing one message while recording another.

Digital memory is available in several varieties:

- EEPROM (Electrically Erasable Programmable Read Only Memory)
- DRAM (Dynamic Random Access Memory) low cost but inefficient and sensitive to power fluctuations.
- SRAM (Static Random Access Memory) low power consumption can be battery backed-up with on-board lithium battery. Recent price drops make SRAM a good candidate for digital memory.

Transmitter

The function of the transmitter is to convert the audio signal from the message record/playback subsystem into a modulated AM radio signal to be transmitted from the antenna. Various classifications of transmitters are available. The power amplification stage of the transmitter is characterized by an alphabetic letter A through D to describe the linearity and efficiency of operation. Class A is the most linear and least efficient, while Class D is essentially switched on and off for various parts of the output signal and hence is the most efficient. Class D transmitters have a typical efficiency of 75%. Greater efficiency results in less heat losses and hence better operation. Efficient transmitters can be kept in sealed enclosures to protect them from dirt and moisture, thereby extending their useful life. Highly efficient transmitters will be more conservative in use of battery power during power outages.

Vertical Antenna Systems

It is desirable to place a HAR antenna in an area that has few obstructions to radio signals. Large buildings, geographic obstructions, trees, metal towers and overhead power lines should be avoided. An ideal site is a flat open field that is several hundred feet across. Good soil conductivity is another important factor. A radio ground plane can be improved with radials composed of heavy gauge copper wire buried about 12 inches below the surface and extending about one hundred feet in all directions from the base of the antenna. Ground rods are usually attached at the ends of the radials as well. Special chemical systems are available to provide a ground plane where available space may be as small as 10 feet in diameter.

The antenna must be tuned to the operating frequency. Both electrical and mechanical means are usually used to adjust the antenna and lead in cable to the transmitter output, to this provides maximum radiation from the antenna.

"Leaky Cable" Antenna Systems

Cable antenna systems are usually run in conduits and either suspended near the roadway or directly buried. A cable antenna is generally considered to be more expensive to install than a vertical antenna. If buried the antenna is easily damaged by roadway construction, roadside guide rail, sign and delineator installations as well as attack from rodents.

System Control

Most systems allow remote control that can be provided either from a touch-tone telephone or a personal computer. Telephone control is accomplished by interpretation of dual tone multi-frequency (DTMF) tones as commands, from a touch-tone phone. Some systems utilize voice prompts to instruct the operator to utilize the remote control features of the recorder and provide status messages. Under computer control, all functions and diagnostics can be controlled from a PC. The control software could incorporate a graphical user interface (GUI) to make system operation clear and intuitive.

Some systems allow the message to be composed and digitized at the PC before transmission to the HAR. The use of such a digital transmission reduces noise that might be introduced by this transmission. The resultant broadcast is clearer and more easily understood.

The communications link between the HAR site and the control point could be standard telephone, cellular telephone, owned cable, radio or fiber optics. Multiple HAR micro-transmitters could be utilized on the same frequency, transmitting the same message, provided that they are carefully synchronized. A fiber optic interconnect could be utilized to provide this means of synchronization.

Most HAR systems are able to operate in a mode that provides live message broadcast should the need arise.

Notification Signs

Signs advising drivers to tune their radios to the frequency required to receive a HAR broadcast should be placed near the edge of the reception area. Signs with flashing attention lights that are activated when an important message is being broadcast may prove useful to motorists.

Kiosks

Another medium for traveler information is the use of kiosks. Kiosks, in this instance, are video screens that display maps and/or text information regarding traffic, incident and transit information. Placed strategically at shopping malls, schools or large places of business: kiosks can provide pre-trip information. This pre-trip information can be used by motorists to plan alternate routes around congested areas or around incidents. Transit users can plan alternate routes with information provided on the status of transit vehicles. Communications from the Traffic Operations Center to the kiosks is vital to the success of a kiosk system.

Dial-In Systems

A useful pre-trip informational tool is the Dial-In System. A telephone number is established for the public to call for current traffic conditions for the ATMS. Usually, the messages are prerecorded with the time and date so the caller knows the age of the traffic information. This system could be set up as a toll free number or as a toll call. Once the call is placed, choices could be given to enter the highway route number or in the case of transit the bus line number. The recording would provide details as to traffic conditions at various interchange locations. Information from the Traffic Operations Center must be fed to the Dial-In System operator to update the recordings.

DATA PROCESSING

Data processing functions primarily consist of analysis of the data gathered by detector equipment in the field, and the use of incident detection algorithms, which use the data gathered by detectors to identify potential incidents. The data processing for each of these functions is discussed in the following sections.

Detector Data Processing

The processing of the data collected from the vehicle detection system requires that a balance be maintained between the location of data available for processing, processing capability, communications circuit loading, and access to the data for analysis and presentation. Three options are typically considered:

1. Transmit the data to a central location every second.
2. Aggregate the data in the field for a specified time period (typically 20 seconds, 30 seconds, or 1 minute) and transmit the aggregated data to the central location at the end of the collection interval.
3. Aggregate the data over a collection interval (20 seconds, 30 seconds, or 1 minute), store this data in the field for an extended time period (up to several hours), and transmit it to the central location when required. The requirement for the data can be based upon an “event” occurring in the field, such as the detection of an incident, or upon the request of the central system.

The first option requires relatively few bits to transmit vehicle counts because of the limited number of vehicles passing by a detector in one second. However, lane occupancy and vehicle speeds require about 10 bits per data item, in order to maintain accuracy. This combination of number of bits to transmit, and the one second transmission frequency places a heavy burden on the communications network (typically 1,200 bps). It also requires a central computer system able to handle the data volumes and the data updates every second.

A second by second update is required when monitoring an arterial intersection controller, or an individual freeway monitoring computer. This monitoring is typically required for only a few such controllers simultaneously, so the overall system design need not provide the capability for every location to communicate with the TOC every second.

Option two utilizes the power and processing capabilities of currently available microprocessors. As the processors that are deployed in field locations become more powerful and less expensive, distribution of the data processing is advantageous. This lessens the load on the communications network, and reduces the need for a larger central computer. The dynamics of traffic flow, and the rate of update of status maps and displays at the TOC establish the frequency of data transmission from the field devices. Operational experience has shown that updates every minute are not frequent enough, and updates every 10 seconds appear to be too frequent. This range has resulted in a 20 or 30 second communications time interval being utilized by several operational systems.

With this option, the field processor collects data for the selected time interval, and stores it in an intermediate data buffer until polled by the central computer at the TOC. There are numerous operational results, levels of service and summaries that can be calculated from the collected data. Since these calculations can be performed at either the field processor or the central computer, there is no advantage of transmitting these derived values to the central system. They can be computed on an as-needed basis at the TOC (or other location) from raw field data less expensively than they can be transmitted. If they are needed at the field processor, for example by a technician reviewing the operation of field equipment, they can be calculated at that time in the field. This requires that the field processor have sufficient memory to store several hours (or days) worth of data. Computer memory in the megabyte (million byte) range is now very inexpensive, allowing this strategy to be implemented.

The data collected from an induction loop in a 20 second period can typically be represented with three bytes of data, and speed/length/classification counts obtained from a speed loop pair require less than six bytes of data. Thus, with six main-line lanes, one entrance ramp and one exit ramp being monitored, six speed pairs and four individual loops would be utilized. This results in about 48 bytes of data, plus overhead of about 20 bytes, being transmitted between the central computer and the field controller each 20 second period.

The case noted above, where second by second monitoring of a controller is required, must be included in the design of a periodic data collection/polling system. Since 20 second data collection and second by second reporting are both equally important, the communications system must be designed to permit ***20*** second data collection to be interwoven with second by second reporting. This interweaving must occur in a manner that does not exceed the delay requirements of either data stream, and fits within the available bandwidth of the communications channel.

The third option is useful when routine, periodic refreshment of status maps or data displays is not required. A data collection example would be the transmission of stored volume/occupancy data from the second loop of a speed loop pair only on as requested basis. Another example would be an incident detection algorithm running in the field microprocessor based upon variations in speed of individual vehicles, detailed data that is lost when speeds are averaged over a 20 second period. Error reporting also falls into this category, since errors are infrequent events and need to be reported only when they occur.

The goal of most traffic monitoring and management systems is to reflect the real-time status of the roadway at the TOC. or other centralized location. This requires that data be transmitted from the field to the central computer on a regular basis. However, as noted in the examples above, there are categories of information that are infrequent (errors or detected incidents), or stored data that is needed only on an occasional basis (on demand), or data that is available in the field processor but normally not used at the central computer (for example, the standard deviation of speed.) All of these situations require that the communications protocol and data formats be flexible enough to allow the system user to request or receive notification of this data when needed.

Example Application

One example of an intelligent transportation system for incident detection is the Tunnel Operations Monitoring And Control (TOMAC) project in Newport News, Virginia. In this case, a TOMAC system was implemented for the Hampton Roads tunnel complex. This control system has been applied at several facilities including the Elizabeth River Downtown and Midtown Tunnels, and the new four tube I-95 Fort McHenry Tunnel in Baltimore.

The system operates with automatic incident detection based on a modified California algorithm using absolute and relative occupancy. Detector communication is performed in one second increments, with a small degree of pre-processing, to convey accurate occupancies. When the software determines that a detected occupancy is likely to have been caused by an incident, the suspected incident is reported to the operator. An adjustable threshold of sensitivity is used. An excessively low threshold can result in a high false alarm rate, however, an overly high threshold may result in missing a real incident. The occupancy threshold is automatically adjusted every four hours to compensate for recurring traffic conditions such as morning and evening peak periods.

When a suspected incident is detected, the location of the suspected incident is identified and the operator is notified. The operator examines CCTV monitors to determine the nature and validity of the reported condition. The required emergency operation procedures are then manually entered. The Fort McHenry version of TOMAC is capable of entering emergency operation procedures without operator intervention, however, the system is not operated in a fully automatic mode. The emergency operation procedures have been developed in a rudimentary expert system that controls variable message and lane use signs in the tunnel. The course of emergency action depends on the current state of the tunnel and the location of the incident. The TOMAC System assists in changing all signs forward and behind the incident to appropriate status. Variable message signs and changeable speed limit signs that have been pre-programmed are commanded for display under the appropriate circumstances.

The ability of TOMAC to detect possible incidents and direct an operator to a specific monitor to observe and verify a possible incident is beneficial in the operation of an automated incident detection and management system.

Incident Detection Algorithms

An incident is usually defined as any event that causes a temporary reduction in the **capacity** of a facility or roadway. Incidents may result from occurrences that physically block a portion of the active roadway or from occurrences entirely off the roadway that cause rubbernecking or friction effects (such as an accident on the shoulder). When a roadway is operating at a level below its capacity due to an incident that reduces capacity but leaves the roadway with enough capacity to handle the existing traffic, there are few effects on operating characteristics and it will be difficult to detect by traditional means. However, if capacity is adequate, the impact of a longer response time, with respect to traffic delay, is less significant.

Various algorithms have been developed to perform automated incident detection. Different traffic parameters are measured and compared in a number of ways, each variation results in a new algorithm.

Traffic Parameters

The standard parameters used to quantify traffic are occupancy, speed and volume.

- Occupancy - The percentage of a given time period that a vehicle covers a particular point on the roadway.
- Speed - The average velocity of vehicles passing a point on the roadway during a given time period.
- Volume - The number of vehicles passing a point on the roadway during a given time period.

Comparisons of different types of time averages considering new data as well as data from adjacent detector stations are the basis for incident detection.

Recurring congestion, due to operation of a roadway above its capacity, may be detected as an incident by some algorithms. A means of incident verification is needed to determine the cause of detected congestion. Incidents that occur on an already congested section of roadway are also difficult to detect, because operation is already below capacity.

Incident detection algorithms measure and compare various parameters of the traffic stream to parameters demonstrated during typical conditions. Traffic tends to flow with a direct linear relationship between volume and occupancy (See Figure 5-1, line segment ab) under normal conditions. In congested operation, the relationship is shifted to restricted flow, resulting in a decreased volume and higher occupancy (See Figure 5-1, line segment cd. Point d represents standstill conditions.)

If an incident occurs at a time that the roadway is operating at point b, the volume will be reduced and occupancy will be increased to provide operation at point c. Downstream of the incident, operation shifts from b to e.

Direction of Incident Conditions

When a queue develops from an incident, a shock wave travels upstream as additional vehicles are added to the queue and a metered wave travels downstream due to decreased volume and occupancy in the free flow after the restriction. The waves eventually reach detector stations where their effects can be sensed.

Detection of the metered wave that travels downstream at the highway flow rate may provide a rapid indicator of the occurrence of an incident. Detection of the shock wave, resulting from queue build-up traveling in the upstream direction, provides further indication of an incident. Normal traffic flows that result in detection of parameters similar to the effects of both the metered and shock waves could be a result of normal bunching of traffic or “noise” in the flow causing false alarms.

The time taken by an algorithm for calculations to provide incident detection is usually not a major factor in detection time. The comparisons between algorithms usually depend on the time that it takes the parameters at the detection stations to reach values that the particular algorithm requires before declaring an incident.

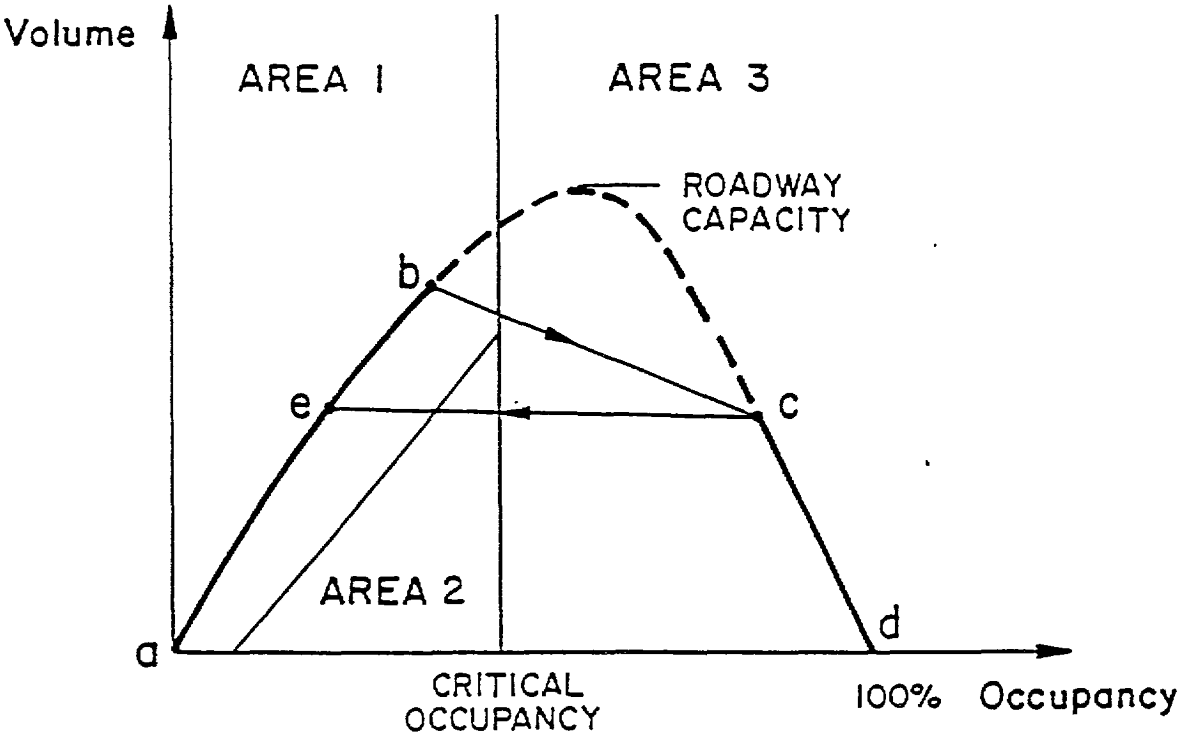
California Algorithm

The California algorithm relies on the detection of three parameters or features between an upstream and downstream detector that are specific to incidents. These features must exceed all three specific thresholds:

- Spatial difference in occupancies (OCCDF), the absolute (arithmetic) difference in occupancies, from data in the same time period, between upstream and downstream detectors.
- Relative spatial difference in occupancies (OCCDRF), a test to determine the relative size of the difference by dividing the absolute difference by the occupancy found at the upstream detector.
- Relative temporal difference in downstream occupancy (DOCCTD), similar to OCCDRF except the test compares downstream occupancies at different times, time (0) and time (-5) seconds.

The modified California algorithm simply uses a different time period for comparison of DOCCTD, the times used are time (0) and time (-2) seconds. This results in a shorter interval used for the comparison test. There are a number of variations that improve some aspects of, or provide additional features for, the basic California algorithm. Some of these variations allow the detection of incident termination, others provide less sensitivity to compression waves in the traffic stream, and others offer improved detection or have lower false alarm rates. A combination algorithm could be developed to provide the features desired at the project site.

Figure 5-1 Fundamental Volume-Occupancy Relationship



AREA 1 = UNCONGESTED OPERATION

AREA 2 = LOW SPEED OPERATION

AREA 3 = CONGESTED OPERATION

Time Series Models

Another class of algorithms uses recent past occupancy history to model, through time series, the near future values of occupancy parameters. When the projections differ by more than the threshold, an incident can be declared. Various statistical measurements of traffic parameters are used to detect incidents. The standard normal deviation algorithm considers the mean and standard deviation of occupancy over a period of about five minutes. An incident is declared when the measured value differs by more than one standard deviation from the mean. The double exponential smoothing algorithm employs absolute error between the observed and predicted value of volume and occupancy for one minute intervals. The ARlMA, or autoregressive integrated moving average algorithm, declares an incident when the observed occupancy is found to be outside the 95 percent confidence limit. The time series approach will detect congestion as well as incidents and does not offer any advantage regarding false alarms

McMaster Algorithm

This is a single station algorithm that operates on two-dimensional classification of flow and occupancy. The algorithm basically relies upon the determination of the roadway operating volume-occupancy region as shown in Figure 5-l. A congestion flag is raised when operation is in area 2 or 3, or a slow highway speed is detected. When the flag is present for a specific number of consecutive periods, a potential incident is signaled. Since speed calculated from a single loop detector is unreliable due to a non-homogeneous traffic stream, most systems use paired loops to extract speed. The logic is claimed more efficient if data is collected from a lane with few or no trucks, as trucks tend to disrupt normal traffic flow. This algorithm tends to be successful at detection of congestion, however, video confirmation is recommended to determine the cause of the detected congestion. Later developments of the algorithm apply comparison logic. Once congestion is detected, a check of adjacent station conditions is used to test for the incident that caused congestion.

HIOCC

Developed for the British UK Transport and Road Research Laboratory. HIOCC seeks to identify slow moving and stopped vehicles. When several consecutive seconds of instantaneous occupancy are found to exceed a threshold, an incident is identified. Separation of incidents from other types of congestion is not performed by the algorithm.

Other Algorithms

There are numerous other algorithms that are either variations on standard algorithms or are experimental and still in development. These include the Minnesota algorithm, which utilizes data filtering and assumes that a large deviation in a system parameter must be caused by a malfunction; the Willsky algorithm, which uses macroscopic modeling of traffic flow; the Cremer algorithm, which models the reduction of capacity at incident locations by considering an imaginary volume input at the incident location; and Algorithm #7, as it has been referenced in the literature, which is an adaptation of the California algorithm. The availability of these and other algorithms is noted although it is not considered here.

Video Incident Detection

Several approaches to incident detection are being applied as a result of video detection capabilities. Video detection offers the possibility of wide area detection from a camera location. One algorithm, called Speed Profile Incident Evaluation System (SPIES) employs several speed traps in each lane of traffic. The speed traps are positioned a few hundred feet apart to allow the system to analyze speed changes within view of the camera. Speed data is gathered and smoothed on the basis of volume resulting in samples about every 15 seconds. The samples are compared with 15 minute data in a historical database. An incident is detected by comparison of speeds measured at the upstream and downstream detectors, with expected speeds from the database and an alarm threshold.

Another video detection algorithm called Autoscope Incident Detection Algorithm (AIDA) uses the variation of traffic flow data with regard to both time and distance. A rapid breakdown such as a speed-drop or occupancy increase and speed thresholds are used to determine congestion levels,

A new type of incident detector has recently been developed for Autoscope by Image Sensing Systems Inc. This incident detector is designed to reside within the Autoscope and can be configured on the unit's monitor in a fashion similar to the way standard detectors are configured. The incident detector will sense an unusual drop in speed coupled with an increase in occupancy. Comparisons are made with recent history using a dynamic threshold which automatically adjusts with the amount of traffic detected. Incident detection is expected to be available as an upgrade to older Autoscope models. Detected incidents will be reported on a serial communications port of the Autoscope using a non-proprietary multidrop protocol.

An evaluation of a traffic scene concentrating on the two dimensional data provided from a video camera is performed by another prototype system, Image Processing for Automatic Traffic Surveillance (IMPACTS). This system evaluates the spatial distribution, movement, and stops of traffic in the field of view. The roadway is divided into small areas called cells. The algorithm determines the magnitude of change for three variables in each cell. Spatial occupancy, weighted occupancy and lane state are tracked and relational changes in these variables are used to detect incident congestion. In a test near London, Great Britain, which ran for 170 hours, a total of 74 incidents were properly detected, two incidents were missed and four false alarms were logged. This system shows good promise for further development.

Conclusions

It appears that for the present, if a high percentage of incidents are to be detected, a high false alarm rate will need to be tolerated. A false alarm rate of one percent will result from one false detection in one hundred tests. If data from the IMPACTS tests are reliable, systems of this type may provide true wide area detection. Since there is little experience with video detection and its ability to perform incident detection, the use of this technology may involve some degree of risk.

Detection algorithms cannot be expected to find every incident, nor can they be expected to perform without false alarms. Automatic detection of incidents provides the operator with a source of information about possible incidents on the roadway. The information obtained must be confirmed and dealt with no differently than any other source of information that may need to be questioned.

Several major factors surface from a study of incident detection algorithms:

- Single station algorithms detect congestion. A secondary means must be used to verify conditions and determine the cause of the congestion.
- A multistation algorithm depends upon the continued operation of each detector. When one station fails, three comparisons cannot be performed. If detector stations are placed every quarter-mile, a half mile section would be lost with a single failure. It should be possible however, to bridge over the failed section and perform the comparisons with data from the adjacent detector stations.
- Incident detection requires that traffic parameters be checked for operation outside of certain thresholds. When data is found that exceeds some threshold by a large margin, an incident could possibly be reported without the need for additional testing. If the threshold is exceeded by only a small margin, further testing is justified. This type of magnitude testing might allow some incidents to be reported more quickly. Some algorithms consider overly large margin variations as probable hardware faults. Tests could be included in any developed algorithm to consider this possibility.
- Variable thresholds may be applicable for various levels of traffic and may be adjusted by time of day and day of week. For example, it may not be desirable or necessary to detect the recurring congestion during the typical peak periods.

STRATEGIES EVALUATION

The heart of a transportation management program is the surveillance sub-system. This sub-system supports three different types of functions: counting and monitoring individual vehicles, analyzing vehicle flow information for incident and subsequent congestion detection, and providing visual images for confirmation, interpretation and analysis.

Various algorithms have been developed to detect incidents (as discussed in the previous section). Most algorithms compare traffic parameters such as vehicle occupancy (the amount of time a vehicle's presence is detected at a particular point on the roadway), speed or volume between adjacent detector stations. The California class of algorithms which do this type of comparison have been used with reasonable success for many years. The McMaster algorithm has been developed to operate with single station detection where specific characteristics of the measured speed, occupancy and volume are used to indicate the existence of congestion. The determination of whether this congestion results from an incident or excess volume also needs to be performed. This determination is not necessary if the highway has excess capacity and is not subject to recurring congestion.

Incident detection and management relies on accurate real-time traffic flow data. A hybrid of automated detection, with computers monitoring detector locations, and human observation using closed circuit television is commonly used for advanced traffic management systems (ATMS). Although each of the sub-systems can work independently, automated detection and visual verification are functions that complement one another. The best performance results from an automated detection system that calls upon a human observer to view a possible incident and determine an appropriate response. As more progress is made in ITS technologies, including image processing, artificial intelligence, and expert systems technology, it is inevitable that computer systems will augment the capabilities of the human observer.

Transmission of information to the motorist is an integral part of an incident management system. This provides the mechanism to alert the motorist of problems ahead, so that an alternate route can be taken. The most commonly used technology installed along the road is the variable message sign (VMS). Another commonly used method to communicate with motorists is highway advisory radio (HAR). Effectiveness of HAR is improved when signs alert drivers to new messages with flashing lights. Dial-in telephone services have been implemented in various forms, and Travelers Advisory Telephone (TAT) is becoming common. An innovative traveler interface has been utilized by some systems involving public kiosks and terminals. Units might be located at convenient locations such as hotels, shopping malls and major workplaces. Direct information about highway congestion and travel time can be provided for user designated routes. General information about area highways might be displayed without specific requests. Cellular telephones are often used to inquire about roadway congestion and to report incidents. Commercial radio and television stations broadcast periodic traffic reports in many metropolitan areas, and studies have shown that this is presently the most commonly used source of traffic information.

Computer equipment and software located at the traffic operations center (TOC) collects and centralizes all the various types of data and information generated by the surveillance sub-system. It also provides a control interface for motorist information sub-systems. Modern computer technology has reduced the size and cost of the computer hardware. However, the complexity of the software continues to increase as the functional demands for graphical user interfaces, and other state-of-the-art features, are included in the overall computer system.

POTENTIAL IMPROVEMENT OPTIONS FOR TRANSPORTATION MANAGEMENT

Potential improvement options for a transportation management system range from capital and operating expenditures to institutional and jurisdictional measures. A wide variety of options are used successfully elsewhere. Although all of these options may not be applicable in Grand Rapids, it is useful to review them prior to selecting a recommended system.

Potential system components can be categorized by the incident management process: detection and verification, response, site management, clearance, and traveler/motorist information. Congestion management options are also important. This section provides information on potential options considered for the Grand Rapids area.

Detection and Verification Options

The sooner an incident can be detected and verified on the primary route, the less impact the incident will have on the normal flow of traffic. Statistics have shown that every minute of roadway blockage can result in five to six minutes of congestion and delay to recover. The following options for detection and verification may be used to bring an incident to the attention of the responsible agencies or authorities:

Dedicated Freeway Service Patrols: Dedicated freeway service patrols (also called motorist assistance patrols). such as the ones currently operating in the Detroit area, are important in areas where timely incident detection and response is particularly critical or where other electronic detection equipment is not available. Many minor accidents and incidents can be cleared with the patrol vehicle, eliminating the cost and delayed response of tow trucks. The supplies carried by service patrols are sufficient to clear many incidents related to vehicle breakdown. In addition, push bumpers mounted on the service vehicle allow for quick clearance of small accidents. However, once the patrol stops at an incident scene, its detection capability on the rest of the primary routes is eliminated. Several private companies have successful organized service patrols. They train the personnel, equip the vehicles, and operate the service. Other freeway service patrols are operated in a similar manner by transportation agencies or by enforcement agencies.

Motorist Aid Call Boxes/Telephones: Motorist aid call boxes/telephones are appropriate in isolated areas, where detection times are lengthy. Reporting can be done 24 hours a day directly to the responding agency. The units can be solar powered with cellular communications. There are, however, sometimes problems such as crank calls and vandalism. Also, the increased use of cellular phones in incident identification has made call boxes impractical in many jurisdictions.

Incident Reporting with Cellular Telephones. Incident reporting with cellular telephones is similar to a "911" system, but may use a different phone number. In many cases. these systems can be monitored by existing dispatch staff, requiring no special training. Motorists usually provide timely information about a particular incident. However, the use of the system is limited to cellular telephone owners, the workload of the dispatcher is increased dramatically, and roadside signs are required to inform motorists of the system and to locate the incident. Capital, operating and maintenance costs are relatively low and the benefits are generally high. To increase these benefits, cellular telephones should be distributed to the transportation agency personnel who frequently use the freeways during commuting hours in return for calls at regular intervals to track travel speeds and report incidents. If the system is set up such that a different number is used for non-injury freeway incidents, a disadvantage of the system is that it requires the motorist to make a decision as to whether the incident is an emergency (in which case 911 should be dialed) or not.

Citizens' Band (CB) Radio Monitoring: Citizens' Band (CB) radio monitoring is similar to the cellular telephone system. Over a dedicated CB channel, these communications can be monitored by service patrol vehicles on patrol as well as by existing police dispatchers. Multiple transmissions will help to verify and locate the incident. Much of this potential is focused on the truck driver. As with the cellular system, there will be an increased workload for the dispatcher, and roadside signs are necessary to inform the CB user of the system. This can also be used to broadcast information to CB users of incident related congestion.

Volunteer Watch: Volunteer watch involves citizen observation of the freeway from vantage points in high incident areas or directly in vehicles calling in observations on a periodic time basis. The advantages of a volunteer watch include visual verification and initial assessment of the incident. Disadvantages might include lack of available volunteers for a particular high incident area, as well as the need for training or instruction to acquire reliable information.

Ties with Transit, Taxi, and Shuttle Companies: Ties with transit, taxi, and shuttle companies can take advantage of vehicles already on the road with two-way radio communications. This method of detection would allow the system to expand to cover the entire city street system in addition to local freeways. In the future if GRATA is able to install Automatic Vehicle Location (AVL) equipment on its fleet, travel times and roadway conditions could be determined. This method of detection and verification requires very little training. Incident data would be reported to the transit, taxi or shuttle dispatcher and relayed to the traffic operations center. The dispatcher would then relay the information to the appropriate agency.

This improves the efficiency of transit, taxi, and shuttle operations in that the dispatcher shares the information with the other vehicle operators. This is a very low cost option that has produced significant benefits in other areas. The benefits of this option in the Grand Rapids area would be limited to the arterials since there is no scheduled service on the freeways.

Aircraft: Fixed wing aircraft are used in many areas for commercial radio traffic updates. This method has potential for monitoring shifts in traffic to diversion routes and visually analyzing traffic distributions. One disadvantage of air patrols is the high cost, which typically limits patrols to peak periods. Also, weather conditions can reduce flying times. The aircraft patrol would provide timely information by calling directly into the traffic operations center. Data compiled at the TOC would be made available to the operators of the aircraft patrols and as well as to operators of vehicle probes providing information to the TOC. Since these types of commercial patrols are not often funded by the transportation agency or police, the exchange of information can result in a high return.

Electronic Detection: Electronic detection includes inductance loops, radar detection units, infrared detection units, microwave detection units, and video imaging detection systems (VIDS). These systems vary in cost, accuracy, and proven reliability. Traffic flow information collected by these devices is sent through a communications link (leased telephone lines, twisted pair wire, fiber optic cable, coaxial cable, etc.) from the detector's roadside processor to a central computer with incident detection software. The advantages of electronic systems include 24-hour operation and traffic data collection capability. Some disadvantages are high initial cost, false alarms, and potentially high maintenance costs.

Closed Circuit Television (CCTV) Closed circuit television provides quick incident assessment, and promotes proper response to incidents. This system also provides a method to record selected incident response activities for later review. Full system coverage of the freeway would require approximately one camera per mile plus additional cameras at interchanges. Manually monitoring these cameras is ineffective. Cameras can be linked directly to detection subsystems to automatically activate an alarm and call up the appropriate camera. Other potential users of a fiber optic cable system, such as universities and private industry, may be contacted to explore the potential of shared funding Also, partnerships with the fiber optics company may be directly pursued.

Traffic Operations Center (TOC): The traffic operations center is a central information processing, dispatch and control site for the management of a transportation system. In a multi-jurisdictional situation, it is advisable to develop one overall TOC, providing better service than several uncoordinated centers. Since the primary function of TOC is information sharing, it is best to link its operations with existing agencies. Ideally, it would include all of the decision makers involved in a major incident. Some of the service patrol vehicles and personnel could also be housed at this center.

Response Time Improvement Options

Identifying the proper response to an incident and getting the appropriate equipment to the scene as quickly as possible are the keys to efficient and reduced response times. Interagency communications and cooperation are very important where fast response is needed.

Personnel, Equipment, and Materials Resource Lists: Personnel, equipment, and materials resource lists provide information on who should respond in each particular jurisdiction. Police, fire, emergency medical responders, transportation, media, and private agency contacts, as well as the method of communication. should be specified. Radio channels and telephone numbers should be clearly identified. This list would be distributed to the appropriate responding agency personnel. The same type of list would be compiled for equipment and materials in the area. These relatively inexpensive tools will save time and effort in the event of an incident.

Dedicated Freeway Service Patrols: See previous section in Detection and Verification Options.

Personnel Training Programs: Personnel training programs emphasize the coordination aspect of incident response, making each agency aware of the other agencies' needs and requirements. A demonstrated willingness to participate and cooperate is required by all agencies if the incident response team approach is to be successful.

Tow Truck/Removal Crane Contracts: Tow truck and removal crane contracts may be established with private firms to reduce the response times at frequent incident locations, and to allow immediate use of necessary equipment. These contracts eliminate the question of who to call when specific equipment is required. Agency owned tow trucks are typically costly to purchase and operate. Private contracts offer financial incentives for the tow truck company to clear the freeway as quickly and safely as possible. Heavy duty wreckers stationed at key points allow for the quick removal of major equipment, debris, and spills. Generally these are warranted for short sections (usually bridges and tunnels) with high truck volumes.

Improved Interagency Radio Communication. Improved interagency radio communication may require the purchase of compatible two-way radio equipment and the use of a common nomenclature or terminology. This would improve site management and provide better information to the responding personnei. However, it may not be feasible for all agencies to participate and to invest in new equipment. Costs vary depending on specific equipment needs. Command posts, such as mobile command centers may be needed at incidents where two or more agencies are involved. This facilitates communications and saves time by reducing repetition of commands.

Ordinances Governing Travel on Shoulders: Ordinances governing travel on shoulders will be possible only in areas where shoulder widths are wide enough for emergency equipment. In order for emergency vehicles to reach the scene of an accident, it may be necessary for vehicles to travel on the shoulder. In some situations during incidents, travel by the public on shoulders to circumvent the incident may be necessary. It would be a wise decision to incorporate sufficient shoulder widths in any redesign projects.

Emergency Vehicle Access. Emergency vehicle access, such as movable barriers and U-turns at key locations along the freeway, reduce response times for emergency vehicles. These techniques are useful for response vehicles when one direction of the highway is completely blocked and access is only possible by approaching the scene contraflow to the travel direction. However, unauthorized motorists may be tempted to use these U-turn facilities, and movable barriers are expensive.

Diversion Route Planning: Diversion route planning is useful when the capacity of the primary route is reduced by an incident. It is important to plan routes that avoid low overpasses or severe turns. Either temporary or permanent signing is required at junctions and along the route to reduce confusion and provide for smooth traffic flow. Use of VMSs and/or HAR to inform motorists of the alternate route is very effective.

Diversion Route Management: Diversion route management is needed to adjust traffic signal timings to accommodate additional traffic flow after a diversion plan is requested. The computerized arterial traffic signal system should incorporate a feature to automatically recommend and/or implement an incident response timing plan. Diversion route management techniques can also be used to locate underutilized alternate routes and redirect traffic to them on a real-time basis.

Equipment Storage Sites: Equipment storage sites would reduce response times by providing special removal equipment at high incident locations. Costs are minimal if this space already exists, but it may be difficult to find additional space at some high incident areas. Large equipment to be stored might include wreckers, sand trucks, and other large vehicles. Smaller items include cones, signs, flares, portable barriers, and other equipment for traffic control.

Administrative Traffic Management Teams: Administrative traffic management teams include officials from transportation, police, fire, and rescue agencies. This strategy requires a willingness to cooperate by all participating agencies. The intent is to provide a forum for discussion of unresolved incident management issues, preplanning for response, and improved communications.

Public Education Programs: Public education programs inform motorists of their rights and responsibilities when they are involved in a traffic accident. Motorists are permitted to move their vehicles from the scene of an accident according to Michigan state law, but may not do so. Most are reluctant to do so in any case because of misconceptions regarding the legality or liability of the action.

Traffic Operations Center: See previous section in Detection and Verification Options.

Closely Spaced Reference Markers: Closely spaced reference markers, as well as other landmark and directional markers, help in locating incidents. These markers aid cellular telephone callers in reporting incident locations, and provide improved record keeping for analysis of incidents. The markers would be located on the center median barrier to enhance visibility and reduce costs of sign posts. For ramps and collector-distributor roadways, special numbering, colors, and/or patterns would be necessary, due to the potential for confusion. Utility poles might also be designated with markers to identify locations along the freeway. These markers might be placed every 1/10 of a mile or every 2/10 of a kilometer.

Site Management Options

Incident clearance can become more effective if the site management techniques are well executed. Coordination of personnel and control of traffic help to reduce the likelihood of secondary accidents.

Incident Response Teams. Incident response teams would be comprised of personnel from various agencies. These teams would be trained to handle unusual incidents and would be familiar with one another. Incident response teams might improve site management and clearance efforts in special circumstances, but they are likely to be ineffective if not properly trained and equipped. Similarly, the effectiveness of incident response teams is limited if refresher courses are not provided frequently, and if there is turnover in agency staff.

Personnel Training Programs: See previous section in *Response Time Improvement Options.*

Improved Interagency Radio Communications. See previous section in *Response Time Improvement Options.*

Properly Defined Traffic Control Techniques: Properly defined traffic control techniques are standard guidelines for lane closure which are identified and agreed to in advance. The guidelines should be consistent with the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices and any superseding state guidance. This action requires cooperation among agencies. The incident management team would provide an appropriate forum for this activity.

Properly Defined Parking for Emergency Response Vehicles: Properly defined parking for emergency response vehicles is a technique of identifying, in advance, the appropriate place at an incident site for placement of response vehicles. This placement depends on the nature of the incident. As with the traffic control techniques, this is a cooperative action. In a related policy, Seattle recommends that emergency vehicles be positioned so as to close no more travel lanes than those already blocked by the incident.

Flashing Lights Policy: Flashing lights policy would be considered to reduce distraction to non-involved motorists. Flashing lights may not be required when the responding vehicles are on the shoulders. The drawback is that the response team members may not feel as safe. Some field testing may be necessary to get reactions from incident response team members and the public, and some legislative work may be required.

Administrative Traffic Management Team: See previous section in *Response Time Improvement Options*

Traffic Operations Center: See section in *Detection and Verification Options.*

Diversion Route Planning: See section in *Response Time Improvement Options.*

Incident Response Manual: An incident response manual would be developed to increase the efficiency of responders activity at the incident site. Input by all involved agencies is required to produce a document that accurately defines all procedures for site management. It should be specific to the facility, roadway or corridor it deals with. Frequent updating and training is also required.

Clearance Time Reduction Options

A reduction in clearance time results in a reduction in vehicle delay. Options to reduce clearance time are presented below.

Policy Requiring Fast Removal of Vehicles: A policy requiring fast removal of vehicles is a low cost method of returning the roadway to normal operating conditions where shoulders exist or where there is adequate space for a holding area. Liability may be an issue if damage to the disabled vehicle occurs, Generally. however, this policy has no cost to the transportation agencies, and would make police and other response personnel available to perform other more important duties.

Accident Investigation Sites: Accident investigation sites allow operable vehicles involved in non-injury accidents to be removed from the travel lanes immediately. In many situations, secondary accidents occur due to blockage of travel lanes. With the use of off-road or out-of-sight accident investigation sites, secondary accidents are less likely. Accident investigation sites are used to interview those involved, fill out police reports, and make necessary telephone calls. The area should be flat and well lighted with a telephone or call box. Finding an appropriate location may be difficult, and site preparation, signing, and publicity will require a degree of investment. Signs along the freeway are needed to inform motorists of accident investigation sites, and education would be required to inform motorists of the use of these sites. These sites are only effective to the extent that they are used by motorists.

Dedicated Freeway Service Patrols: See section in *Detection and Verification Options.*

Push Bumpers: Push bumpers can be added to the tow trucks, emergency service patrols and police vehicles. They are especially beneficial for quick clearance along elevated roadways and sections with inadequate shoulder widths.

Responsive Traffic Control Systems: Responsive traffic control systems, such as the computerized traffic signal system currently in use in some cities, will aid in diversion route management. When diversions become necessary, the traffic operations staff would implement or request implementation of a pre-determined traffic signal timing plan which would provide more capacity to the diversion route for the duration of the incident.

Ordinances Governing Travel on Shoulders: See section in *Response Time Improvement Options.*

Emergency Vehicle Access: See section in *Response Time Improvement Options.*

Diversion Route Planning: See section in *Response Time Improvement Options.*

Incident Response Teams: See section in *Site Management Options.*

Personnel Training Programs: See section in *Response Time Improvement Options.*

Incident Response Manual: See section in *Response Time Improvement Options.*

Administrative Traffic Management Teams: See section in *Response Time Improvement Options.*

Public Education Program: See section in *Response Time Improvement Options.*

Total Station Accident Investigation Equipment: Total station accident investigation equipment is a combination of electronic surveying and distance measuring devices developed exclusively for the investigation of accidents. This type of equipment reduces delays, personnel requirements and exposure of personnel to traffic hazards since accident investigations can be carried out more quickly.

Traveler/Motorist Information Options

Communication with travelers is an important component of any intelligent transportation system. Options for communications include the following.

Highway Advisory Radio (HAR): Highway advisory radio is a powerful instrument to share information with travelers in their automobiles. Information regarding planned lane closures due to construction or maintenance is broadcast repeatedly over the HAR. Advanced warning to motorists of lane closure schedules, incidents, or special events will help to reduce the traffic demand at the closure, and may reduce the number of accidents in the area. HAR transmitters would be needed to provide coverage for motorists in and around the metropolitan Grand Rapids area. If a high power transmitter is used, motorists can be informed prior to their trip.

Variable Message Signs (VMS): Variable message signs are used alone and in conjunction with HAR to inform motorists of planned lane closures, incidents and special events. Truck mounted or trailer mounted VMS can be very effective in incident management. These can be located and moved in response to a major long term incident.

Traffic Operations Center: See section in *Detection and Verification Options.*

Commercial Radio and Television Broadcasts: Commercial radio and television broadcasts are good sources of information for the traveling public in most cases. Commercial radio is a well known source for traffic information in the metropolitan Grand Rapids area. In some communities, commercial broadcasts have been known to provide outdated or incorrect information.

Kiosks: Kiosks may be used for special traffic generators such as shopping malls and large employment buildings, and could be used to inform motorists of traffic conditions. On-screen graphics and text could convey accident and incident information, travel times, or even provide suggestions for the best route to a motorist's destination.

PC/Modem: PC/Modem systems could be used to tap into the TOC's computer from home or work. A telephone hotline would be established so that travelers could call in for conditions on the primary route. A caller would enter the route number, the entry and exit interchange number and the direction of travel using a key pad or mouse. The computer would dispatch information to the caller on current roadway conditions. Private sector firms could become involved in establishing this service. Or, the information could be located on an Internet home page, automatically being updated every few minutes.

Congestion Management Options

Several techniques exist for decreasing congestion on freeways. Ramp metering can be used to divert traffic that utilizes the freeway for short trips and can also smooth out the flow of traffic on the freeway. High occupancy vehicle (HOV) lanes can be implemented to move more people in fewer vehicles by providing exclusive lanes on the mainline and queue by-pass lanes at congested interchanges especially from freeway to freeway. Predictive algorithms can be used to balance traffic between freeways and alternate arterials within a corridor.

Ramp metering requires analysis and determination of congested sections of freeways. A threshold of volume to capacity ratios (V/C) would be determined to identify congested segments. Congested segments would be linked together to form a larger section. The ramps within this section as well as several ramps upstream of the beginning of the section will be field checked to determine the length of queued vehicles that could be stored. To properly deploy ramp metering, it may be necessary to reconstruct those ramps which have very little storage length. Detectors on the ramps for queues spilling back onto local streets, detectors at the stop bars near the signal heads, and the controller and cabinet are the equipment needed for ramp metering. In some cases, detection in the right lane of the freeway upstream of the ramp is used to identify available gaps in the mainline .

High occupancy vehicle (HOV) lanes can be deployed in areas where existing carpool, vanpool and bus traffic would benefit from an exclusive lane. At interchanges where on/off ramps are congested, queue by-pass lanes could be implemented for HOVs. This would provide an additional travel time incentive Congested areas of freeways could be equipped with an HOV lane where travel time savings would be at least one minute per mile, and overall travel time savings would be at least eight to ten minutes per trip.

By instrumenting the freeways and the parallel arterials, predictive algorithms could be utilized to balance traffic flow between the freeways and the parallel arterials. Variable message signs (VMS) and highway advisory radio (HAR) could be used to send messages to the motoring public regarding which route is less congested or which route is more congested. The algorithm predicts when the less congested route will become more congested and relays the message to the VMS and HAR to stop shifting traffic. This balancing may change from time of day or time of year and may be based upon historic data as well as sensor information that counts the number of vehicles shifting.

PUBLIC TRANSPORTATION TECHNOLOGIES

This section addresses ITS transit technologies and their applications in the Grand Rapids metropolitan area.

Advanced Public Transportation Systems (APTS) is the program name describing the application of advanced navigation and communication technologies to transit system operations. APTS applications can assist transit system managers provide timely accurate information on transit services to transit passengers, and improve the efficiency, reliability and safety of the service.

APTS applications are often summarized into three categories:

- Smart traveler technology, which focuses on the provision of basic user information to transit users before they make decisions on how they will make a particular trip. An important objective is to make real-time information available through the use of advanced computer and communications technology.

- Smart vehicle technology, which involves the integration of various vehicle-based technologies to improve vehicle and fleet planning, scheduling and operations.

- Smart inter-modal systems, which combine APTS technologies with traffic management and other non-transit applications. The objective is to create multi-modal transportation networks to optimize the transportation system as a whole.

Many APTS technologies exist; the most popular APTS applications are:

- Automatic Vehicle Location (AVL) and Computer Aided Dispatch (CAD). AVL utilizes one of several technologies to determine the location of transit vehicles and relate this location information to scheduled location and time. Through specialized data processing and communications, this information is integrated with CAD to achieve improved operations control and management. AVL is the APTS technology with the most applications throughout the industry.

- Smart Cards. These are personal debit cards that can be used for payment media for other modes and parking lots, as well as transit fares.

- Automatic Passenger Counting (APC). APC employs devices that keep track of transit patrons as they board and exit vehicles. and relate this activity to a place (the specific transit stop) and time.

- Automatic Stop Annunciation. This application provides audio announcements of the next stop, transfer points, areas of interest at stops, and other information useful to transit patrons. Automatic stop annunciation is often used to assist transit system managers meet Americans with Disabilities Act (ADA) regulations regarding the provision of stop information to persons with visual impairments.

- Passenger Information Systems. This area covers a broad range of applications that involve the provision of transit user information in an enhanced manner, including interactive systems and real time information. APTS projects in this category include interactive kiosks at stops and stations, automated telephone systems and the use of various electronic media, such as cable television.

- Adaptive Traffic Signal Control. This involves providing transit or traffic managers a degree of control over traffic signals by transit vehicles to provide preference over general traffic, thereby reducing transit travel time and improving reliability.

Other examples of the use of technology in transit are not usually regarded as APTS or ITS applications. For example, automated fixed route scheduling systems are not usually included, although these automated management aids can be integrated with AVL systems and passenger information systems resulting in more effective application of these APTS technologies. Automated paratransit scheduling and dispatching systems are categorized as APTS if they employ advanced communications and navigational technologies.

AVL is the most widely used APTS-type application, probably because it is the only one that has been economically justified from a public investment standpoint. AVL's capability to make vehicle scheduling more effective can result in the amortization of AVL's initial cost in three to five years.

In addition. AVL represents infrastructure in that other APTS applications require data from an AVL system. For example, passenger information systems providing real time service information integrate passenger displays with vehicle location information from an AVL system.

The linking of APTS technological applications with similar applications relating to traffic management and control has the ability to enhance the operation of both modes, and generate greater benefits for transit passengers and automobile users.

Transit related ITS user services identified by representatives of GRATA as the highest priorities are:

- Public Transportation Management
- Ride Matching and Reservation
- Public Travel Security

En-route Transit Information and Personalized Public Transit user services were identified as medium priorities.

En-Route Transit Information

Although the user service identified by transit agency representatives is termed En-Route Transit Information, it appears the need exists to improve and coordinate all forms of transit user information. A deficiency of accurate, readily available, user information appears to exist.

GRATA currently operates a telephone information services providing route information. GRATA is also a primary sponsor of the "RIDE-LINE", a central telephone information and referral service for special transportation in Kent County. RIDE-LINE assists callers in determining which transportation program can best meet their needs and refers the individual accordingly.

An alternative to the current situation would be to use technology to enhance the operation of the regional transit information center. Telephone information systems are very labor intensive and represent a significant operating cost. Budget limitations result in limited information services, in terms of the number of agents available to take calls, hours operation and days of operation. Technology is available to automate telephone information systems. making them more efficient and potentially reducing costs. A number of commercially available systems exist, ranging from automated tools to assist information agents, to full automation.

The majority of calls that are made to transit information centers are for simple schedule information, such as the scheduled time of the next bus on a specific route. These calls can be readily answered through a caller select key pad based system, or "audiotext". Areas that have used automated systems also maintain traditional information systems with agents who can address more complex requests for information involving transfers among routes, and other matters not readily addressed by automated responses.

An Advanced Traveler Information System (ATIS), such as the one in place in the Boston metropolitan area, would provide information for highways as well as transit. An ATIS would be capable of providing the comprehensive transit user data desired by the public, but such a system would require transit operators to provide information in some type of electronic format for use by the ATIS.

User information can be provided en-route in a number of different ways. Several APTS operational tests have assessed the use of electronic kiosks at transit stops, or high activity areas near transit stops. These interactive devices allow access to transit information while the user is making the trip. The results of these tests have been inconclusive. Other operational tests have explored the use of electronic signs and displays at stops with the capability of providing real time information (e.g., through interconnection with an AVL system) or messages controlled by dispatchers (e.g.. in the event of service interruptions or reroutes). These tests have also been inconclusive to date.

GRATA previously provided electronic information at major transfer stops. It was discontinued because the information changed frequently and could not be kept current. GRATA is considering reinstating the service.

For the most part, the need for en-route information can be provided through low-tech solutions. For example, static displays of printed transit schedule materials provided at transfer locations can assist transit customers as they transfer from one route (or system) to another. Public telephones, or dedicated information center phones. located at bus stops and transfer centers can provide the important link between the customer and information needed to complete a trip.

Public Travel Security

Increasingly, concerns about security appear to be having a negative affect on transit's ability to attract and maintain customers. This became more of a concern in 1992 when GRATA began transporting substantial numbers of Grand Rapids Public Schools students. While the decision made good economic sense for both the school system and GRATA, it has resulted in other problems which may have adversely affected general ridership. These problems primarily have to do with student behavior and interaction with drivers and other passengers.

Public travel security can be addressed through technology applications in several ways. AVL technology allows transit dispatchers to direct supervisory and law enforcement personnel quicker in response to incidents reported by bus drivers, often using a silent alarm feature. Other transit operators estimate that AVL reduces response time by up to half.

Electronic video and audio surveillance is increasingly being used to monitor activity on board buses. Two way radio systems used by transit operators can be equipped with covert microphones that are activated when a silent alarm is engaged. Conversations between the bus driver, passengers and persons causing disruptions can be monitored and used by dispatch personnel in responding to an incident.

Some transit systems in other metropolitan areas use video cameras mounted in the interior of buses. Typically the video is not monitored. Instead, the video is recorded, saved and can be monitored at a later time if an incident occurred on the bus. The video cameras have been deployed as a deterrent, but have allowed authorities to identify individuals responsible for criminal offenses, as well.

Video surveillance can also be used to monitor activity at transit stations and bus stops, and at facilities such as park and ride lots. With the large number of bus stops maintained by GRATA (1,800 to 2,000 individual stops) video surveillance is practical only at heavily used bus stops, such as transfer locations and downtown area stops. Video cameras used in this manner usually require monitoring by security personnel, adding to operating expense.

Whether or not ITS-type applications are used, coordination between transit agency dispatch centers and law enforcement control centers is a requirement for improved public travel security. Coordination including standard operating procedures, mutually accepted agency and individual roles, and improved communications between dispatch personnel.

Public Transportation Management

Public transportation management, a high priority among transit operators in the metropolitan area, can include a large number of applications. Generally, technology applications that have the potential to reduce costs, improve service, and address specific problems or objectives in the Grand Rapids metropolitan area should be considered.

GRATA is considering the implementation of an Automatic Vehicle Locator (AVL) and is planning on implementing a system within three (3) years, if funding can be obtained. Discussions have also occurred between GRATA and the City of Grand Rapids regarding a trial implementation of a bus preemption system for the traffic signals. In addition to producing benefits itself, AVL represents technological infrastructure that can be built upon with other applications to produce even greater benefits.

Beyond these efforts, other opportunities exist in the general area of public transportation management improvements.

Paratransit Scheduling and Dispatching

Another opportunity to use technology to improve public transportation management is in paratransit scheduling and dispatching. GRATA manages and oversees GO! Bus special transportation for seniors and persons with disabilities who meet eligibility guidelines. GRATA manages and oversees GO! Bus, including user eligibility, trip reservations, and service monitoring. The service is provided by three private transportation carriers under contract to GRATA. A new system for paratransit scheduling was obtained in 1995. Coordination and even consolidation of public information, reservation, scheduling and dispatch functions holds potential for significant improvements in service from the public's perspective.

Paratransit services are much less productive in terms of passengers carried per hour, compared with traditional fixed route transit service. This low productivity is a result of the tailored nature of the service. Typically each passenger trip is individually reserved and scheduled. The number of trips per hour is a key variable in the cost of these demand responsive paratransit services. Experience from other metropolitan areas has shown that automation of these tasks can result in significant improvements in the productivity of demand response paratransit systems. For example, one large operator of demand response service in the St. Louis metropolitan area reported a 75% increase in productivity, measured in passengers per mile, after implementing a fully automated scheduling and dispatch system.

Chapter 6
Benefits and Costs

INTRODUCTION

This chapter provides estimates of the benefits and costs that would be expected due to implementation of a freeway management system in the Grand Rapids metropolitan area. The second section of this chapter provides a background to benefits experienced with other ITS implementations in other areas. System benefits due to a freeway management system, discussed in the third section, are presented for the full implementation of the freeway management system. Costs associated with a freeway management system, discussed in the fourth section, include both capital and operating expenses, and are provided as the summation of the component costs that comprise the system. The benefit cost ratios for the freeway management system are presented in the fifth section.

BACKGROUND[1]

The first implementations to some of the user services included in the current ITS structure began appearing in urban areas in the late 1960's. Implementations since then have become more flexible, more capable, and more integrated. For example, incident management programs that began as courtesy patrols and CB monitoring have incorporated new technologies and are increasingly being integrated into transportation management centers.

Implementations of ITS programs have demonstrated benefits to address the national program goals in the areas of safety, productivity, efficiency, and environmental impact. Benefits are derived from a smoother flow of traffic with less delay from signals, incidents, and traffic queues. Most aspects of the implementations contribute to time savings.

Experience with past ITS program implementations have shown positive results. For example, Incident Management Programs have shown an eight (8) minute decrease in incident clearance time, a l0%-20% decrease in travel time, and a 10% decrease in fatalities in urban areas. According to draft analyses based on data from the Fatal Accident Reporting System, reduction of incident notification times on urban freeways from the current average of 5.2 minutes to 3 minutes would reduce fatalities 10% annually.

Implementations of ITS programs are justified by user benefits and are evaluated against other no-build options. As an approximate comparison, freeway expansion costs $2 million per lane mile while a complete implementation of an urban corridor costs $500,000 per freeway mile plus the cost of a freeway management center. If the existing freeway is four lanes, installing a traffic management center could add about half the capacity of an additional lane at about l/8 the cost.

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1 Information on the background of ITS benefits was obtained from *Intelligent Transportation Infrastructure Benefits: Expected and Experienced* USDOT. Operation Timesaver, January 1996.

ESTIMATED BENEFITS

The estimated benefits for the implementation of the freeway management system in Grand Rapids include reductions in travel delay time, fuel consumption and automobile emissions. The benefits are calculated for each phase of the freeway management system implementation. In order to help prioritize areas for improvement, the benefits are also shown on a per mile basis.

The benefits in the short term are based on 1993 ADT values as documented in the MDOT Sufficiency Ratings. The Long Term benefits are based on 2015 volumes provided by GRETS. The Medium term benefits are based on volumes extrapolated from the 1993 and the 2015 projected volumes. The number of accidents is assumed to grow at the same rate as the ADT's over the time frames in order to best estimate the benefits of the system in future conditions.

A number of assumptions were necessary to estimate the annual benefits. While these assumptions affect the absolute magnitude of the benefits, they do not affect the relative magnitude of the benefits. Thus, they are not critical with respect to identifying which segments would be expected to result in the greatest benefit. However, because these assumptions affect the magnitude of the estimated benefit, they do affect the benefit cost ratios and will impact the recommended time frame for implementation and the extent and kinds of technologies that would appear to be warranted. Additional information regarding the calculation of the benefits, including the assumptions used, is included in Appendix D.

Travel Delay Time

The primary benefits expected to result from the implementation of a freeway management system are travel time savings that would result from a decrease in incident response time. A reduction in the time that elapses before an incident is identified and located would be expected due to the implementation of freeway surveillance equipment, including roadway detectors and closed circuit television (CCTV).

Incident response would also be facilitated by the provision of information to emergency responders. Information from the CCTV would help emergency responders decide what kind of equipment is needed at the scene. This would decrease vehicle delay by both assuring that the equipment needed arrives quickly and minimizing the transport of unnecessary equipment to the scene which would reduce capacity by further obstructing traffic flow. Information from the CCTV could also be used to determine the best method of access for emergency responders. Sometimes accidents are best accessed from surface streets that are close to the freeway or from the freeway lanes in the opposite direction. Finally. information on current travel speeds could be used to help determine the best route for emergency responders.

Benefits also accrue as a result of informing motorists about traffic conditions. Variable message signs, highway advisory radio, and the provision of current and accurate traffic information through commercial radio and television are all valuable mechanisms for communication with the public. Although it is difficult to predict the magnitude of the impact of this information, it does have an impact. In addition to reducing driver frustration, it can also affect travel behavior.

In fact, almost half of respondents using a traveler advisory telephone service reported that the information they received had a direct effect on their travel behavior.’

Studies completed in other areas have reported a 20-50 percent reduction in incident induced travel delay times resulting from the implementation of freeway management systems. For this analysis a conservative approach was taken to estimating the benefits that may be obtained by implementing a freeway management system. It is assumed that during incidents causing delay, a 25 percent reduction in travel time delay would result from the implementation of a freeway management system. It is also assumed that the average queue length during an incident in the Grand Rapids area is three (3) miles and the average speed in the queue is 10 mph. The percentage of the total traffic that will experience delays due to accidents depends on where the accident occurs and at what time it occurs. For accident sensitive areas (areas highlighted in Figure 2-9), it is assumed that 40 percent of the ADT will encounter 30 percent of the total number of accidents. This is based on the assumption that approximately 10 percent of the ADT occurs during each of the a.m. and p.m. peak hours when accidents are most likely to cause significant delay. It is further assumed that an additional 20 percent of the ADT is likely to encounter delay causing incidents, primarily during the midday period. Another set of assumptions was made concerning the frequency of accidents and the percentage of accidents that are likely to cause delay. The first assumption was that 40 percent of the recorded accidents occurred during the time that 40 percent of the ADT was on the road. The second assumption was that 75 percent of those accidents would cause delay. Taking 75 percent of the 40 percent of the accidents expected to occur during the heavier traveled periods resulted in 30 percent of the total recorded accidents for each segment being used in the calculation of travel time delay. Similarly, for those areas not highlighted in Figure 2-9, it is assumed that only 10 percent of the ADT is likely to encounter delay causing accidents and that 10 percent of the recorded accidents will cause the delay. Table 6-l summarizes the annual benefits expected from travel delay time savings.

Table 6-1 Travel Delay Time Savings

Roadway	Miles Covered	Travel Delay Savings (million)	Travel Delay Savings per Mile (million/Mile)
us 131	19	$6.83	$0.36
I-96	20	$0.55	$0.03
I-196	13	$1.33	$0.10
Total	52	$8.71	$0.17

2 Summary of Findings. Massachusetts Highway Department Independent Evaluation of SmarTraveler Operational Test (conducted for the Massachusetts Highway Department and presented in a paper to ITS America).

Fuel Use and Emissions

Benefits are also expected to result from a decrease in fuel consumption and related automobile emissions due to the implementation of the freeway management system. These benefits correspond to the travel delay time savings in that they are the direct result of improved incident response and management.

The average fuel efficiencies are assumed to be 15 miles per gallon when the speeds are under 35 mph. The cost of fuel is estimated to be $1.20 per gallon. The assumptions regarding the average speed, length of queue and percentage of ADT encountering congestion are the same as mentioned for the travel delay time benefits. Table 6-2 summarizes the annual benefits expected from fuel use savings.

Table 6-2 Fuel Use Savings

Roadway	Miles Covered	Fuel Use Savings @million)	Fuel Use Savings per Mile @million/Mile)
us 131	19	$0.73	$0.04
I-96	20	$0.06	$0.003
I-196	13	$0.14	$0.01
Total	52	$0.93	$0.02

Vehicle exhaust emissions can be reduced due to the reduction of incident related congestion. Research which was conducted by Partners for Advanced Transit and Highways (PATH) and the South Coast Air Quality Management District shows that vehicles emit various amounts of CO, HC, and NO, emissions according to their speed. Figure 6-l describes the amounts of emissions versus velocities generated by vehicles on the average. From the graphs, using a speed of 10 mph, the following emission rates were extrapolated:

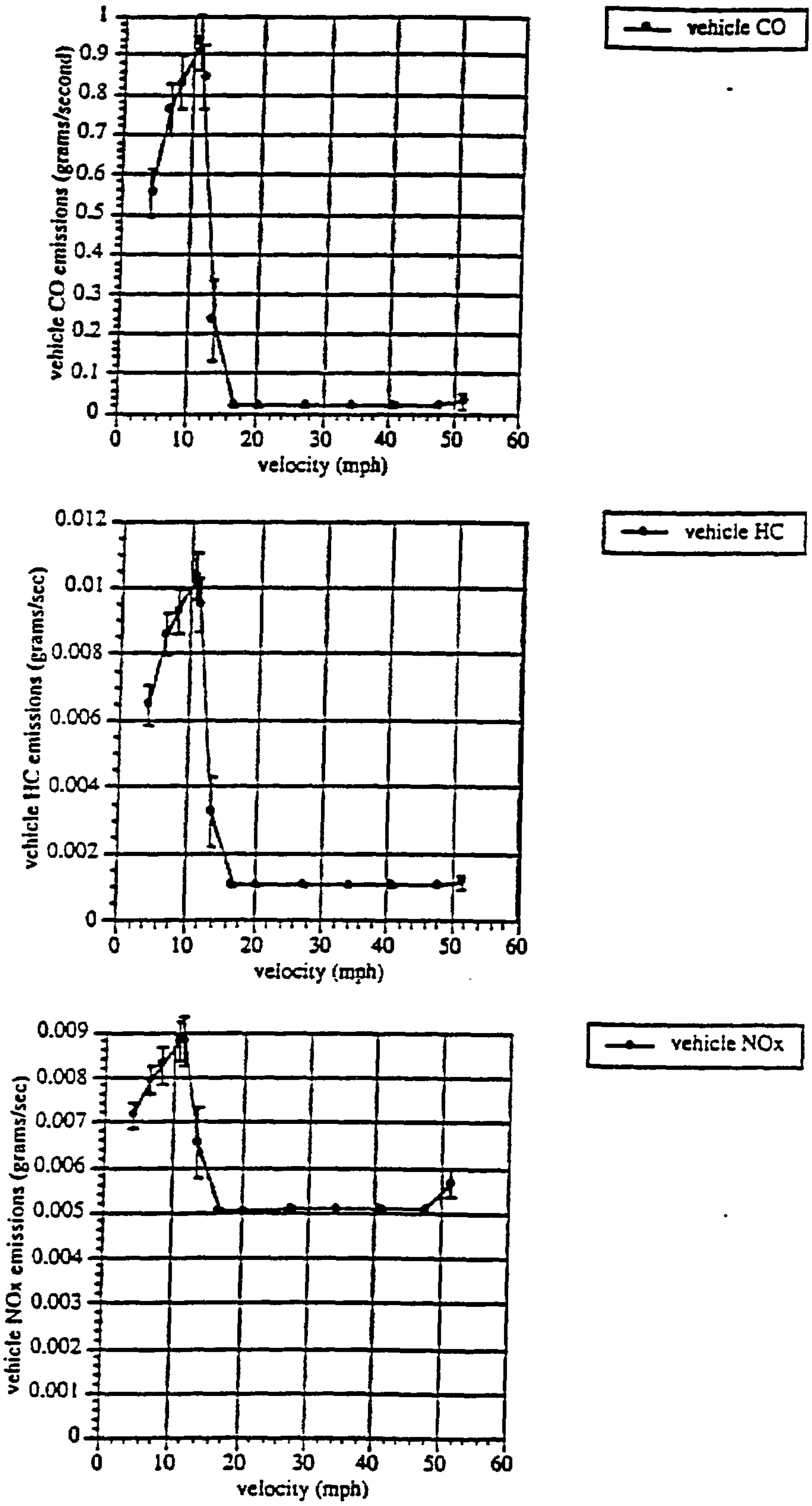
Emission	Emission Rate
CO	0.94
HC	0.01
NO_x	0.0085

Table 6-3 shows the reductions in these emissions.

Table 6-3 Emissions Savings

Roadway	CO Emission Savings (Tons/yr.)	HC Emission Savings (Tons/yr.)	NOx Emission Savings (Tons/yr.)
US 131	2,546	27	23
I-96	207	2	2
I-196	497	5	4
Total	3,250	34	29

Figure 6-1 Velocity vs. Emission Curves



SOURCE: University of California, Riverside

Total Benefit

The total annual benefits for each roadway and each phase are summarized in Table 6-4. Note that the benefits are higher on the highways with higher volumes and accident rates. This is due to the fact that benefits would accrue to a greater number of vehicles where both volumes and incidents are higher. Benefits are highest on US 131, especially within the S-Curve (see Table 6-5).

Table 6-4 Benefits Per Phase

Roadway	Short Term*	Medium Term*	Long Term* Total	Benefit*	Benefit/Mile*
US 131	$6.69	$0.87	$0	$7.56	$0.40
I-96	$0.35	$0	$0.24	$0.61	$0.03
I-196	$1.27	$0.21	$0	$1.47	$0.11
TOTAL	**$8.34**	**$1.08**	**$0.24**	**$9.64**	**$0.19**

* Benefits in millions of dollars

Table 6-5 Benefits Per Roadway Segment

Facility	Roadway Segment		Volume (ADT)	Number of Accidents	Seg. Length (Miles)	Annual Benefit/ Mile	Time Frame
	From	To					
US 131	68th St.	Wyoming Limits	66,100	18	0.96	$123,442	Med.
	Wyoming Limits	54th St.	66,100	18	0.78	$12,628	Med.
	54th St.	44th St.	70,700	19	1.27	$105,349	Med.
	44th St.	36th St.	83,100	20	1.01	$163,411	Med.
	36th St.	28th St.	90,000	56	1.01	$498,000	Short
	28th St.	G. R. Limits	104,000	40	0.53	$786,216	Short
	G. R. Limits	Burton St.	104,000	17	0.51	$343,261	Short
	Burton St.	Hall St.	107,000	51	0.98	$553,480	Short
	Hall St.	Franklin St.	114,000	47	0.52	$1,023,218	Short
	Franklin St.	Wealthy St.	115,000	35	0.43	$934,476	Short
	Wealthy St.	Market St.	121,000	48	0.54	$1,065,335	Short
	Market St.	M-45	128,000	61	0.27	$2,880,284	Short
	M-45	I-196	125,000	59	0.57	$1,284,178	Short
	I-196	Leonard St.	108,000	78	0.92	$913,976	Short
	Leonard St.	Ann St.	108,000	39	0.76	$553,450	Short
	Ann St.	I-296 Conn.	99,000	27	1.02	$261,267	Short
	I-296 Conn.	I-96	56,000	29	0.87	$185,707	Short
	I-96	Walker Limits	61,000	23	0.58	$240,101	Short
	Walker Limits	West River Dr.	61,000	33	0.84	$239,540	Short
	West River Dr.	Post Dr.	55,800	79	3.98	$110,233	Short

Facility	Roadway Segment		Volume (ADT)	Number of Accidents	Seg. Length (Miles)	Annual Benefit/ Mile	Time Frame
	From	To					
I-96	16th Ave.	Kent Cty. Line	3,760*	l0*	2.00	$1,318	Long
	Kent Cty. Line	Fruit Ridge Ave.	39,700	12	1.49	$2,654	Long
	Fruit Ridge Ave.	Walker Ave.	59,300	19	1.70	$5,501	Long
	Walker Ave.	Rte M-3	64,500	25	2.12	$75,614	Long
	Rte M-3	I-296	98,000	4	0.16	$248,643	Short
	I-296	US 131	43,000	15	0.98	$65,287	Short
	US 131	Walker Limits	43,000	8	0.27	$129,292	Short
	Walker Limits	M-44 Connector	78,000	15	1.36	$7,167	Long
	M-44 Connector	Leonard St.	56,000	31	3.47	$4,152	Long
	Leonard St.	I-196	39,000	5	0.80	$2,018	Short
	I-196	M-37, M-44	83,000	17	0.47	$300,933	Short
	M-37, M-44	M-21	69,000	14	0.61	$157,727	Short
	M-21	Cascade Rd.	77,390	26	1.61	$10,367	Long
	Cascade Rd.	28th St.	51,150	46	2.91	$6,706	Long
I-196	Kent Cty. Line	44th Ave.	49,850	14	0.62	$9,298	Med.
	44th Ave.	Chicago Dr.	52,650	32	1.39	$10,097	Med.
	Chicago Dr.	28th St.	70,500	25	1.04	$169,118	Med.
	28th St.	Business 196	63,250	22	1.72	$6,719	Med.
	Business 196	Market St.	45,000	12	0.32	$14,229	Short
	Market St.	Rte. M-45	41,000	25	1.53	$66,944	Short
	Rte. M-45	Lane Ave.	41,000	26	0.78	$136,998	Short
	Lane Ave.	US 131	66,000	18	0.70	$169,277	Short
	US 131	Business 131	77,000	42	0.59	$546,870	Short
	Business 131	College Ave.	77,000	14	0.54	$198,831	Short
	College Ave.	Fuller St.	70,000	43	0.87	$344,593	Short
	Fuller St.	I-96	80,000	26	2.00	$103,584	Short

*No data from sufficiency files. Estimated to be 80% of adjoining segment.

ESTIMATED COSTS

The cost estimate for the freeway surveillance system includes both capital and annual operating and maintenance costs. Capital costs reflect the need for freeway surveillance equipment, which includes both CCTV and vehicle detection equipment; variable message signs; highway advisory radio, which includes both transmitters and advisory signs with flashing lights; power distribution and communications to system components; field data processing equipment; a traffic operations center; and centralized hardware and software. Costs are based on the information provided in Appendix C.

Tables 6-6 through 6-7 show the cumulative capital costs and operating and maintenance costs, respectively, associated with each phase of implementation. Table 6-8 summarizes the cumulative cost of implementation for all phases while table 6-9 summarizes the incremental cost of implementation for each phase. All costs indicated are in 1996 dollars. Capital costs were converted to equivalent annual costs, assuming a 15 year life and an interest rate of 6 percent. In general, the quantities shown in Table 6-6 correspond to the quantities indicated in the deployment plan and shown in the figures in Chapter 7. The exception to this is for closed circuit television cameras, which for cost purposes are estimated for placement once every mile. Only selected (priority) locations for each phase are indicated in the deployment plan.

Table 6-6 Estimated Capital Costs for Each Phase (in millions)

		Initial	Short-Term	Medium-Term	Long-Term
	# of miles:	10	22	35	52
Roadway Surveillance Equip.					
CCTV:	cost/site	$0.030	$0.030	$0.030	$0.030
	freq./mile (# of sites)	(12)	1	1	1
	Total	**$0.36**	**$0.66**	**$1.05**	**$1.56**
Detection:	cost/site		$0.010	$0.010	$0.010
	freq./mile		2	2	2
	Total		**$0.44**	**$0.70**	**$1.04**
Variable Message Signs					
	Cost/site	$0.145	$0.145	$0.145	$0.145
	freq./mile	8	8	13	20
	Total	**$1.16**	**$1.16**	**$1.89**	**$2.90**
	Relocate 2 Signs	**$0.15**	**$0.15**	**$0.15**	**$0.15**
Communications					
	CCTV CODECs	$0.175			
	fiber cost/mile	$0.240	$0.240	$0.210	$0.193
	Total	**$2.58**	**$5.28**	**$7.35**	**$10.04**
Highway Advisory Radio					
Transmitters	Cost/site	$0.020	$0.020	$0.020	$0.020
	# of sites	10	10	10	11
	Total	**$0.20**	**$0.20**	**$0.20**	**$0.22**
HAR Signs	Cost/sign	$0.005	$0.005	$0.005	$0.005
	# of signs	29	29	29	32
	Total	**$0.15**	**$0.15**	**$0.15**	**$0.16**
Field Data Processing Equipment					
Intelligent:	$/processor		$0.020	$0.020	$0.020
	freq./mile		2	2	2
	Total		**$0.88**	**$1.40**	**$2.08**
Operations Center					
	cost/sq.ft.	$100	$110	$110	$110
	sq.ft./center	500	6,000	6,000	6,000
	Total	**$0.05**	**$0.66**	**$0.66**	**$0.66**
Central Hardware (Distrib. Center)					
	base cost		$0.440	$0.440	$0.440
	cost/mile		$0.002	$0.002	$0.002
	Total	**$0.07**	**$0.48**	**$0.51**	**$0.54**
Software					
	Total	**$0.07**	**$0.50**	**$0.75**	**$0.90**

Table 6-6 Estimated Cumulative Annual Capital Costs for Each Phase (continued)

Subtotals for 15-Yr. Life	$4.79	$10.56	$14.80	$20.25
Contingency 10%	$0.48	$1.06	$1.48	$2.02
Design and Implementation	$0.82	$1.79	$2.80	$3.94
Subtotal Construction Cost	**$6.08**	**$13.40**	**$19.07**	**$26.21**
Capital Recovery Factor (6%)	0.10296	0.10296	0.10296	0.10296
Cumulative Annual Cap. Costs:	**$0.63**	**$1.38**	**$1.96**	**$2.70**

Note: All costs are in millions of dollars except for the Operations Center, which is in dollars per square foot.

Table 6-7 Estimated Cumulative Operating and Maintenance Costs for Each Phase

	Initial	Short-Term	Medium-Term	Long-Term
Operations Center Personnel				
Manager	$0.050	$0.050	$0.050	$0.050
# of managers	1	1	1	1
Total	**$0.050**	**$0.050**	**$0.050**	**$0.050**
Assistant Manager				$0.045
# of asst. managers				1
Total				**$0.045**
Operator	$0.030	$0.030	$0.030	$0.030
# of Operator	2	2	4	4
Total	**$0.060**	**$0.060**	**$0.120**	**$0.120**
Secretary/Clerical	$0.032	$0.032	$0.032	$0.032
# of Sec./Clerks	0.5	0.5	0.5	0.5
Total	**$0.016**	**$0.016**	**$0.016**	**$0.016**
Maintenance Personnel				
cost/maintainer	$0.035	$0.035	$0.035	$0.035
# of maintainers	1	2	2	3
Total	**$0.035**	**$0.070**	**$0.070**	**$0.105**
Motorist Assistance Patrol				
Total	**$0.175**	**$0.175**	**$0.175**	**$0.175**
Leased Phone	**$0.07**			
Dial-up Phone	**$0.013**			
Factory Repair & Spare Equip. (calc. as a percent of hardware costs)				
Factory Repair %	5%	5%	5%	5%
hardware cap. costs		$3.28	$4.75	$6.68
Total	**$0.067**	**$0.16**	**$0.24**	**$0.33**
Spare Parts %	3%	3%	3%	3%
hardware cap. costs		$3.83	$5.64	$8.05
Total	**$0.041**	**$0.11**	**$0.17**	**$0.24**
Cumulative Annual Operating and Maintenance Costs	**$0.53**	**$0.65**	**$0.84**	**$1.09**

Table 6-8 Cumulative Cost Summary for Each Phase (in millions)

Phase	Initial	Short-Term	Medium-Term	Long-Term
Annual Cost (in millions)				
Capital	$0.63	$1.38	$1.96	$2.70
Operating and Maintenance	$0.53	$0.65	$0.84	$1.09
Cumulative Totals per Phase	$1.16	$2.03	$2.80	$3.79

Table 6-9 Incremental Cost Summary for Each Phase (in millions)

Phase	Short-Term	Medium-Term	Long-Term
Annual Cost (in millions)			
Capital	$1.38	$0.58	$0.74
Operating and Maintenance	$0.65	$0.19	$0.25
Incremental Totals per Phase	$2.03	$0.77	$0.99

* Initial System included in Short term Phase

BENEFIT COST RATIOS - FREEWAY MANAGEMENT SYSTEM

Table B-10 shows the cumulative benefit cost ratio for each phase of the project. Benefit cost ratios must be greater than one in order for the project to be justified. If the whole freeway management system were to be installed immediately, the complete system would have a benefit cost ratio of 2.55. This indicates that the complete system is justified for implementation. Note that the benefit cost ratio decreases between the short term and the long term. This is due to the fact that the short term implementation will impact a greater number of motorists as opposed to the medium and long term plans.

In order to quantify the true impact of the phased implementation expenditures, Table 6-l 1 shows the incremental benefit cost ratio for each phase. This indicates the anticipated amount of benefits from each individual phase. Based on this analysis, the short and medium term plans are justified, however the long term plan is not justified for implementation based on forecasted conditions. If the future growth in Grand Rapids is more than the forecasted growth shown here, it is likely that the benefit cost ratio will increase and will justify implementation within the Long Term time frame. Therefore, this plan should be reevaluated in the future.

Table 6-10 Cumulative Benefit Cost Ratio for Each Phase (in millions)

Phase	Short-Term	Medium-Term	Long-Term
Annual Benefits (in millions)	$8.33	$9.41	$9.64
Annual Cost (in millions)			
Capital	$1.38	$1.96	$2.70
Operating and Maintenance	$0.65	$0.84	$1.09
Total	$2.03	$2.80	$3.79
Benefit Cost Ratio	**4.10**	**3.36**	**2.55**

Table 6-11 Incremental Benefit Cost Ratio for Each Phase (in millions)

Phase	Short-Term	Medium-Term	Long-Term
Annual Benefits (in millions)	$8.34	$1.07	$0.24
Annual Cost (in millions)			
Capital	$1.38	$0.58	$0.74
Operating and Maintenance	$0.65	$0.19	$0.25
Total	$2.03	$0.77	$0.99
Benefit Cost Ratio	**4.10**	**1.39**	**0.24**

Chapter 7
IMPLEMENTATION

FREEWAY MANAGEMENT APPLICATIONS

This section focuses on the implementation of components of a freeway management system. This implementation plan is based on the system architecture developed and described in Chapter 4, the technologies discussed in Chapter 5, and the benefits and costs evaluated in Chapter 6.

Short, Medium, And Long Term Priorities

The short, medium, and long term priorities for the transportation system in the Grand Rapids area correspond closely to the short, medium, and long term ITS user services identified in the User Service Plan and discussed in Chapter 3. These priorities are reflected in the implementation schedule, which is discussed in the next section. Short term priorities include priorities that should be addressed in the next five years. Medium term priorities should be addressed in five to ten years. Long term priorities should be addressed in ten years or more.

Short Term Priorities

Priorities for the short term focus on existing problems and identified needs. Thus, priorities include the need to respond to incidents, which account for a significant amount of congestion in the Grand Rapids area, and the need to identify locations of recurring congestion.

Short term priorities would be met by a number of activities including implementation of a freeway surveillance and management system in selected corridors in the Grand Rapids area and coordination of the freeway management system with the use of arterials for diversion. It is recommended that local jurisdictions, in cooperation with MDOT, initiate activities that would support the use of local arterials as alternate routes to the freeway. Activities include determination of appropriate timing plans for diversion route arterials identified in the Incident Management Plan and the initiation of activities to obtain funding to develop the diversion timing plans. A final short term priority is enhanced institutional coordination, which will be necessary for a coordinated and comprehensive approach to transportation management, and will also be a critical component for the success of future activities. More detailed information about activities and projects to support short term priorities are discussed in the next section, *Implementation Schedule.*

Medium Term Priorities

Priorities for the medium term focus on expanding the framework that has been laid out in the short term, and addressing conditions that might be expected in the foreseeable future. Medium term priorities include expanding the geographic extent of the proposed freeway management system, expanding the freeway traffic management system to consider ramp metering where appropriate, broadening the scope of incident management activities to better address the special requirements posed by hazardous materials incidents, and expanding the kind of information provided to travelers in an effort to not only inform, but also to have a greater influence on traveler behavior.

Another medium term priority is to further integrate the freeway system with the arterial and transit systems in the metropolitan area. This priority implies additional coordination with the traffic signal system in Grand Rapids for the upgrade to advanced or adaptive signal control on arterial routes that will be used for diversion from the freeway. This also implies the provision of transit information in addition to freeway information for trip planning purposes.

Long Term Priorities

Long term priorities generally address issues that are not currently critical problems, and may include taking a proactive approach to potential problems. Long term priorities include the expanding the freeway management system to encompass the entire metropolitan area, implementation of technologies related to commercial vehicle applications, and the implementation of programs, technologies and facilities which would provide an alternative to the single occupancy vehicle. High occupancy vehicle facilities and advanced ride matching programs are just a couple of ways to encourage alternatives to the single occupancy vehicle.

Implementation Schedule

The primary focus of the implementation plan is a freeway management system. System components have been identified for a freeway management system that provides coverage of the entire metropolitan area. implementation of the components is recommended to be staged over phases, with the initial layout shown in Figure 7-l. Conceptual layouts for the placement of variable message signs (VMS's), highway advisory radio (HAR) transmitters and signs, traffic detectors, and closed circuit television cameras (CCTV's) are shown in Figures 7-2, 7-3, 7-4 and 7-5, respectively. The locations identified in Figures 7-2, 7-3, 7-4 and 7-5 are color coded to reflect the recommended staged implementation. Following a brief discussion of the basics of a freeway management system, each phase is addressed as it relates to implementation in the short, medium, and long term.

Freeway Management System

The proposed freeway management system and its components address short term priorities by meeting the need for incident detection, verification, and response.

When the system is fully implemented, incident detection will be provided by detector station locations every half mile. Computer algorithms will automatically process the data from these detectors, displaying real-time travel speeds, and providing notification of unusual traffic characteristics that might indicate an accident or incident. Incident detection may also be provided by other means, such as motorist assistance patrols (MAP) and cellular phone calls. The limitation of these mechanisms is that they do not provide continuous monitoring of conditions, and thus they cannot always be relied upon.

Incident verification will be provided by CCTV. This visual verification will provide not only information about the nature of the accident and the kind of equipment needed, but it also will allow positive identification of incident location. Visual image detection (VID), which consists of CCTV and computer algorithms that analyze the visual image to determine operating characteristics, may also provide incident detection capabilities, and may be a viable alternative in the near future. While some systems currently use VID in conjunction with other means of detection, no system currently relies solely upon VID.

Incident response includes any action taken as a consequence of the situation on the freeway. It may include contacting emergency responders through 911 or the dispatch of MAP, as well as all resulting communications with motorists, such as messages on HAR and VMS's, and information provided to traffic reporting agencies.

Short Term

Activities identified for implementation in the short term include all activities and projects to be implemented within five years. In addition to short term activities, priority “early winner” activities have been identified for implementation within two years.

The primary activity in the short term is the implementation of a freeway management system on the high priority corridors, including the US-131 corridor and I-196 through downtown Grand Rapids. These facilities all carry high traffic volumes. Consequently, any breakdown in traffic flow due to an incident or construction can have significant impacts in terms of delay. Additional and more specific activities to be implemented in the short term are as follows.

- Permanent variable message signs, highway advisory radio transmitters and signs, detector stations, and CCTV cameras should be installed as shown in Figures 7-2, 7-3A and B, 7-4 and 7-5. Priority locations for CCTV cameras and HAR transmitters and signs are shown in Figure 7-1. Cost estimates include additional cameras (one every mile) for complete coverage of the freeways. Please note that the technologies identified for deployment are primarily on the freeways. Additional information on the installation of VMS’s, HAR transmitters and CCTV cameras is provided in the next section, *Guide to Deployment.*

- Milepost markers and overpass signing should be installed on all facilities in the metropolitan area, with priority corresponding to implementation phase. Milepost markers should include route and directional information and should be placed every one-tenth of a mile on facilities with a high accident rate or high volume, and every half-mile on less traveled freeways. Location identifiers should be placed on all ramps.

  Cellular telephone users can be educated about the system through informational inserts in cellular telephone bills and public service announcements. Dispatchers at 911 answer points will also need to be instructed as to how to interpret the information and solicit the information needed from callers.

- A permanent traffic operations center (TOC) should be established for the metropolitan area. This center may be located in the new Michigan State Police District 6 headquarters. Additional information on the TOC is provided in a later in the *Operations Plan* section.

- Weather information should be available at the TOC.

- Traffic conditions should be provided to traffic reporting agencies and to television and radio stations. The provision of traveler information directly to motorists via telephone and/or the Internet should also be explored. It might be possible to partner with a private entity for the provision of a highway advisory telephone service, this could be similar to the existing “time and temperature” phone number.

- A radio link should be provided for communication between the traffic operations center (TOC) and emergency responders after incident response has been initiated. Initial contact between the TOC and emergency responders should be made through the existing 911 system. The TOC should be connected to the 911 tandem computer, so calls can automatically be placed to the appropriate agency. TOC personnel would need to identify the location (possibly via a touchscreen map of the metropolitan area), and the kind of emergency responder needed (fire, police, or medical), and the call would automatically be directed to the appropriate agency.

- The TOC should work with interested local public works agencies and emergency responders to establish video feed from the CCTV cameras controlled by the TOC to the local agencies and dispatch centers.

- Activities conducted by the TOC that are related to incident management should be in accordance with the guidelines established in the *incident Management Plans* for the US-l31 and I-96 corridors.

Initial System

An Initial System is included in the Short Term Plan and consists of priority activities which are recommended for implementation within the next two years. These projects represent activities that are relatively low cost with a short development time, relatively high priority, and address the core infrastructure elements. The initial system projects are expected to be successful, and will enhance the public image of ITS, setting the stage for future projects.

- Several components of the Short Term plan are recommended for implementation in the Initial System for priority locations. A limited number of CCTV cameras and variable message signs are recommend at some of the more congested and accident prone segments, which includes Route 131 and I-196 through the downtown area, and major diversion points in the metropolitan area. A highway advisory radio system is also recommended to provide traveler information throughout the area. The recommended locations for these components are shown on Figure 7- 1.

  The proposed HAR system should be coordinated with the existing system owned by the Town of Holland and maintained by the Holland Chamber of Commerce. There are two basic options to accomplish the coordination. First would be to have the Chamber of Commerce continue operating the HAR and for it to be notified by the TOC in the event of an incident. The second option would be to provide control capability both at the Chamber of Commerce and at the TOC. Under either option the existing HAR control hardware should be upgraded to be compatible with the proposed equipment in the Grand Rapids area to accept the downloading of messages and provide instantaneous replay of the messages from the traffic operations center. Due to the need to provide traveler information in a timely manner, the second option is recommended since it would allow the HAR message to be changed by the TOC during hours the Chamber of Commerce is not open.

  Additional HAR transmitters are recommended to provide information to tourist traffic coming to Grand Rapids from the western lake-shore and for travelers along the US 31 corridor. These transmitters should be placed in strategic locations to inform motorists of problems with the bascule bridge in Grand Haven or of major incidents in Grand Rapids. The conceptual locations for the transmitters are shown in Figure 7-3B. It is recommended that the TOC share the control capability of these transmitters with the local jurisdictions. Further coordination will need to take place with the local jurisdictions and MDOT prior to implementation.

- In addition to the permanent VMS's shown in Figure 7-1, it is recommended that portable VMS be procured by MDOT. These signs can be used to provide en-route driver information and to facilitate incident management during severe incidents of significant duration. These signs can also be used to enhance traffic management during construction and other pre-planned events.

- Implementation of the motorist assistance patrol (MAP) to provide full coverage of the US-131 corridor during the peak hours is recommended. The coordination of MAP activities with other activities in terms of incident response and traffic control, as well as the sharing of information with traffic reporting agencies and any other entities that can enhance communications with the public, is strongly recommended.

- Continued use of the 911 system should be evaluated to determine if there is a need for a separate phone number for non-emergency freeway situations. Some emergency responders have expressed concern that the 911 line has and will become increasingly busy with non-emergency freeway related calls. Proponents of separate systems state that non-emergency traffic related calls are not the purpose of the 911 system, and the high volume of non-emergency calls may compromise the service to emergency calls. A separate telephone number for non-emergency incidents (for example, *66) is recommended in order to ease the burden on the 911 system. Cellular telephone users can be educated about the system through informational inserts in cellular telephone bills and public service announcements. The separate number would be answered at the TOC. The information received from these calls would then be disseminated by the TOC to the motorist assistance patrols or maintenance personnel as appropriate. A disadvantage of this system is that it would require motorists to make a decision as to which number to call.

- Legislation and regulations to facilitate the prompt removal of disabled and abandoned vehicles and freight from the freeway main lanes and shoulders are recommended in Grand Rapids. The clearance times specified should vary depending on incident location (urban vs. rural), time of day (peak vs. off-peak), and day of week (weekend vs. weekday). Michigan currently has legislation that allows MDOT and enforcement agencies to remove a vehicle left on a public highway after 48 hours or when the vehicle interferes with highway operations. This legislation could be enhanced by regulations that iterate specific and more stringent clearance times for facilities in urban areas. Removal times for commercial vehicles and freight should also be iterated, allowing the agency having jurisdiction to initiate clean up activities at the expense of the trucking firm or the entity responsible for the incident. Prompt removal of disabled vehicles and freight in the right-of-way would facilitate incident management and reduce vehicle delay.

- Traffic signal timing plans appropriate for freeway diversion should be developed for the alternate routes that have signal control hardware to support implementation. The Grand Rapids area currently has a unique multi-jurisdictional agreement where the City centrally controls the traffic signals both inside and outside of the City limits. This allows most of the signals in and around Grand-Rapids, including those on diversion routes, to be controlled at one (1) location.

- Increased coordination among neighboring jurisdictions is also recommended for construction activities. Neighboring jurisdictions do not always coordinate construction activities, thus alternate routes are sometimes under construction at the same time that the major route is, limiting the number of routes available.

- Standards for construction and reconstruction projects should be developed to reflect the needs of an intelligent transportation system. These standards would accommodate future needs that could easily be accommodated during roadway and/or shoulder construction and reconstruction activities. Standards should include design considerations for interchanges to make provisions for conduit for power distribution and communication to ITS elements, as we!! as provisions for pull boxes. With respect to conduit for fiber optics, appropriate applications would include freeways and arterial diversion routes that do not have fiber optics, as well as connections from field equipment to the fiber optic backbone.

  Similarly, construction and reconstruction activities should consider the needs of emergency responders during incident management activities. For example, it is recommended that provisions for fire hoses be included in a!! noise walls that will be constructed or renovated in the metropolitan area. These holes should be located so that they correspond with fire hydrant locations, and should be marked clearly. These holes would allow fire fighters to easily access the fire hydrants, facilitating response to freeway incidents involving a potential fire hazard.

- MDOT should pursue activities for the procurement of a fiber optics communications backbone on al! major freeways in the Grand Rapids area. The possibility for a public/private partnership, such as with TCI during their proposed system upgrade to fiber optics, and the possibility of coordinating with local businesses should be examined as a mechanism for reducing costs.

- A policy regarding the provision of traveler information should be developed. This policy would initially address issues such as whether alternate routes should be provided to motorists, and should evolve to address related issues in the future, as needed. This policy should also address price issues, for example whether al! information should be provided without charge, or whether some users should pay a price for specialized information. In the future, for example, it may be appropriate to charge private entities who request the information in a certain format and then provide the information to customers for a fee.

- A partnership with a private entity (discussed in the *Funding* Issues section) should be considered as an option for the provision of traveler information, especially in the short term. This kind of partnership would allow a system to be "up and running" in less than a year, and would not require that MDOT dedicate staff or space to an interim traffic operations center.

- Efforts should be made to coordinate with planning agencies to assure that local and regional plans incorporate ITS concepts. Coordination activities should be initiated with the Grand Rapids and Environs Transportation Study (GRETS) to assure that ITS projects are incorporated into the Transportation Improvement Plan. Coordination with local planning agencies should also be initiated to assure that they understand ITS and how local applications can work together with ITS applications in the Greater Grand Rapids area.

- With respect to the TOC, design activities for the proposed Michigan State Police Headquarters should consider inclusion of a TOC to serve the entire Grand Rapids metropolitan area. Thus, coordination will be required with MDOT. Ideally the facility would be sized to be large enough to serve the entire metropolitan area. At the very least, the proposed facility should be constructed to accommodate the needs of the implementation of the Medium Term Plan.

Medium Term

One primary activity in the medium term is the expansion of the freeway management system. This would extend coverage on US-131, I-196 and I-96. Additional and more specific activities to be implemented in the medium term are as follows:

- Permanent variable message signs, highway advisory radio transmitters and signs, detector stations, and CCTV cameras should be installed as shown in Figures 7-2, 7-3A, 7-4 and 7-5. Additional CCTV cameras may be needed for complete coverage.

- The TOC hardware (monitors and switching equipment) and software should be expanded, as needed, to accommodate the additional freeway coverage.

- Incident data should be compiled and examined to determine if there are any patterns with respect to hazardous material incidents. For example, whether hazardous material incidents are more prevalent at certain locations, such as near manufacturing plants, railway junctions or freeway sections with limited geometrics, and whether any particular kinds of hazardous material warrant greater tracking. If analysis indicates that some locations or types of hazardous material are disproportionately affected. appropriate action may be action. Such action may entail increased monitoring of "problem" sites, or increased tracking of "problem" substances. Activities related to hazardous material incident response and planning should be conducted with input from local hazardous material incident response agencies.

- Efforts should be made to provide transit information, such as information on transit schedules, in conjunction with traffic information. This information may be provided via Internet or telephone, depending on the methods by which highway information is provided. The TOC need not directly be involved in the provision of this information, however, it will need to coordinate with transit entities so that this information may be provided through the central information server and/or other means of information dissemination.

Long Term

One activity for implementation in the long term is complete coverage of the metropolitan area with a freeway management system. Extension of the freeway management system to all major freeways in the urban area would allow re-routing of through traffic around congested areas, and would allow traffic management on a system wide basis. However, relatively low volumes on many of the Long Term Plan facilities imply a relatively low benefit cost ratio at the present time and in the near future. Eventually, however, growth in traffic volumes, as well as decreasing prices for technologies, would be expected to result in more favorable benefit cost ratios. Additional and more specific activities to be implemented in the long term are as follows.

- Permanent variable message signs, highway advisory radio transmitters and signs, detector stations, and CCTV cameras should be installed as shown in Figures 7-2, 7-3A, 7-4 and 7-5. Additional CCTV cameras may be needed for complete coverage.

  Benefit cost ratios should be used to guide the priority of implementation for the long term plan. These ratios should be re-calculated in the future to reflect the actual volume changes, changes in accident rates, and changes in the price of equipment. Installation of equipment for freeway surveillance and verification on a!! facilities will result in complete coverage of the metropolitan area.

  Efforts should be made to coordinate the provision of information from the TOC with the provision of traveler services and other tourist information. This may include information kiosks at the airport and the new arena. This may also include integrating current traffic information into computer "yellow page" system which direct tourists to locations they select. For example, travelers could obtain information about all local Chinese restaurants as well as current travel times to each restaurant. It would even be possible to allow tourists to make "real-time" dinner reservations, so the restaurant could know they are coming and have their table ready when they arrived.

- Efforts should be made to coordinate the provision of information from the TOC with the provision of in-vehicle information, including en-route driver information and route guidance information. Although the TOC may not directly interface with in-vehicle devices, they should coordinate with private or other entities to provide this information. Under this scenario, current travel speeds could be used to determine the route with the shortest travel time.

- Technologies to facilitate commercial vehicle operations should be considered for implementation. Although many of these would be implemented by enforcement and administrative agencies, the TOC may benefit from interaction with commercial vehicle entities. In Minneapolis, the traffic management center currently provides information to commercial vehicles. These vehicles, in turn, serve as spotters by notifying the traffic management center of accidents or unusual travel conditions.

- Implementation of technologies to encourage alternatives to single occupancy vehicle (SOV) commuting should be considered for implementation. The provision of real-time car-pool matching and flexible transit routing and scheduling are just two examples of possible activities. The provision of high occupancy vehicle facilities should also be considered. Although these activities may be primarily conducted by GRATA and GRETS. information about these activities should be available through the information server.

On-going

There are a number of activities that should be on-going in the short, medium and long term. These activities reflect the need for institutional coordination as well as system evaluation.

- It will be necessary for the TOC to coordinate with local public works agencies and emergency response entities. In the future, it may also be necessary for the TOC to coordinate with transit providers for the exchange of information.
- As local jurisdictions acquire more sophisticated equipment, the need for the exchange of information will increase. For example, the TOC may desire signal timing information for traffic signal controllers operated by the city on alternate route arterials.
- The TOC will need to coordinate with emergency responders on an on-going basis. As more emergency response agencies acquire automatic vehicle location (AVL) systems, the TOC may wish to use these systems as probes to indicate travel speeds, especially on segments of the system without detectors or surveillance equipment. On the other hand, emergency responders may wish to use travel time information from the TOC to determine which vehicle and route should respond to a call.
- Although transit vehicles currently do not use the freeway, the TOC still should coordinate with local transit agencies. For example, the Grand Rapids Area Transit Authority’s (GRATA) future AVL system may be used to provide information to the TOC about alternate routes in their jurisdiction. Furthermore, it would be logical to expect that the TOC’s information server would be a point source for information on all modes in the greater Grand Rapids area in the future. Thus, coordination will then be even more important.
- Once the City of Grand Rapids has completed its traffic signal system upgrade, the TOC must work with the city to develop signal timing plans and policies. These plans and policies must be evaluated and modified, as necessary.
- Local agencies must notify the TOC of any construction or maintenance activities that would interfere with the use of an arterial as a diversion route.
- The detectors installed as part of the freeway management system should be used to gather information on “before” and “after” conditions. This information can be used for decision making for later study phases, to verify estimated benefits, and to increase the accuracy of projected benefit cost ratios.
- Data gathered by the freeway surveillance system can be used to identify the location, severity and duration of recurring congestion. This detailed data can be used to assess the need for and project the effectiveness of strategies such as ramp metering.
- The impact of the provision of traveler information, including information about recurring congestion, incident related congestion, and alternate routes, may be evaluated using freeway data gathered by the freeway surveillance system.

Guide to Deployment

This is intended to be a guide for locating Intelligent Transportation System equipment along roadways in the Grand Rapids metropolitan area. This section addresses a number of issues, including diversion routes, variable message signs, CCTV cameras, detection equipment, arterial traffic control systems, HAR, and ramp metering.

With respect to equipment, currently available state-of-the-art technology should be employed whenever possible. However, value engineering should be used to determine the most cost effective equipment to be used. The cost of training, maintenance and operations are also important criteria that should be considered.

Variable Message Signs (VMS 's)

The kind of VMS required and the recommended placement of the sign varies depending on the type of facility. Possible locations for VMS's for each phase are shown in Figure 7-2.

On freeways, VMS's should be placed prior to interchanges with other freeways or arterials for route diversion information. VMS's should be placed approximately three-fourths of a mile prior to the alternative route decision point, keeping in mind the sight distance necessary to read a three-panel message at the prevailing speed of the facility. Special attention should be given to vertical and horizontal curves.

In general, VMS's should not be located prior to interchanges with roadways that have little or no capacity to accept the diverted traffic.

Highway Advisory Radio Transmission (HAR)

It is recommended that a system of individual HAR transmitters be deployed to cover the entire area. A conceptual layout of HAR coverage is provided in Figures 7-3A and B (approximate radius shown is 3 miles).

For the transmitters in the immediate Grand Rapids area, the transmission ranges should be set and the transmitters should be located such that the messages are received by those using the information. There are two approaches to accomplish this, the first and recommended approach is to use a single frequency for the entire metropolitan area. Under this scenario, drivers would be able to access information anywhere in the metropolitan area on the same frequency, minimizing confusion. A disadvantage of this is that there can be only one message for the whole network. A second approach is to use different frequencies for adjacent transmitters. This approach allows more complete coverage, but requires drivers to know where they are and know the associated frequency, changing the radio station as they enter a new HAR coverage area.

For those transmitters in the Holland and Grand Haven areas, it is recommended that a single frequency be utilized to minimize motorist confusion. However, if the transmitters are spread adequately apart, different messages may be played as needed or desired by the local operating agency.

Closed Circuit Television Cameras (CCTV)

On freeways, CCTV cameras should be placed to allow complete coverage of the roadway. This may require spacing as frequent as one every mile. The stage implementation of the CCTV cameras is shown in Figure 7-5. The cost estimate includes provisions for additional cameras, and is based on a frequency of one per mile for complete coverage, CCTV priority locations include high accident locations and interchanges with other freeways, and interchanges with major arterial roadways. More than one CCTV camera may be needed at some interchanges. These CCTV cameras would be used to verify the conditions of interchanges to diversion routes before, during and after a diversion plan. In many cases, the capacity of the interchange will be unable to accept the additional traffic volume, especially at peak traffic times. The CCTV images could be used to determine whether diversions should be used and/or continued or discontinued.

CCTV cameras should be considered for placement at diversion route interchanges with freeways. These CCTV cameras would be used to verify the condition of the diversion route interchanges before, during and after a diversion plan is implemented. In many cases, the capacity of the interchange will be unable to accept the additional traffic volume, especially at peak traffic times. The CCTV camera images could be used to determine whether diversions should be used and/or continued or be discontinued. CCTV cameras located on arterials may be implemented and shared with cities, providing an opportunity for shared costs and benefits.

Diversion Routes

Ideally, choices for traffic diversion routes should be prioritized as follows:

- First: Freeway to Freeway
- Second: Freeway to Major Arterial Roadway

The key to mitigating the impact of diverted traffic on any one roadway is to provide the information as wide spread as possible to the motorists. This allows the motorist to choose the diversion route well in advance of the incident. Providing information to the motorist about the extent of the queue developed by the incident may help motorists decide whether to stay on their route to reach their destination.

If the alternate route has not been instrumented, then manual means of monitoring the alternate route should be deployed until the alternate route has been instrumented. This can be accomplished through roaming service patrols and cellular call-in by motorists to the Traffic Operations Center.

An analysis of the capacity of the available adjacent alternative roadways should be performed. A list of criteria which would eliminate a roadway from being an alternative route is as follows:

- Single lane in each direction.
- School located along the route.
- Hospital located along the route.
- No traffic signals to control or use to artificially increase capacity for diverted traffic.
- Limited overhead clearance for large vehicles.
- Limited turning radii for large vehicles.
- Substandard roadway alignment or geometrics.
- Lack of shoulders.
- Residential areas.
- Heavy pedestrian traffic.
- Active railroad crossings.
- Substantial change in speed limits.
- Circuitous routes.
- Roads which require resurfacing and/or reconstruction.

Possible diversion routes are included in the attachment to the US 131 Incident Management Plan. Due to the limited number of freeways in the area, most of the diversion routes utilize arterials.

Traffic Volume, Travel Speed and Traffic Density Detection Systems

Detection equipment should be deployed along the freeways. Detection equipment may also be deployed along segments of roadways that act as links between alternate routes. These detection systems would provide valuable information with regard to travel speeds and traffic volumes to determine the usefulness of a link for diversion purposes.

Detection Systems should be deployed on freeways at one-half mile intervals or between interchanges. Whenever possible, detection equipment should be employed that is non-intrusive to the flow of traffic. This provides detection equipment that can be installed, operated and maintained with minimal disruption to traffic flow.

On diversion routes that are major arterial roadways that are at least two lanes per direction, detection systems could be used to evaluate the capability of the arterial to handle the additional capacity resulting from freeway diversion. Such systems may be appropriate for implementation in the future by cities or other agencies with jurisdiction, however such systems are not currently recommended.

Expansion of Arterial Traffic Signal Systems

The traffic signal control system should be expanded to include all signalized arterials that may be used as alternate routes. These alternate routes should be designated mutually by the city or agency with jurisdiction and by MDOT. Key arterial diversion routes are all shown in the Incident Management Plans for the US- 131 and the I-96 corridors.

Management of the coordinated arterial traffic signal system will depend on agreements worked out with each jurisdiction. The City's multi-jurisdictional agreement should be expanded to the jurisdictions not currently included.

The city and MDOT should work together to determine an appropriate timing plan prior to an incident. These timing plans should then be evaluated and modified, as necessary.

It is also important that issues related to liability be addressed prior to implementation. Records of all changes in signal timing will need to be kept, and issues related to agency liability will need to be addressed thoroughly.

Ramp Metering

Ramp metering is recommended for consideration in the medium term for congested facilities in the Grand Rapids area. Ramp metering requires detailed evaluation of peak period mainline and ramp characteristics, this information will be available through the surveillance system implemented in the short term. Furthermore, because ramp metering often faces public opposition, it is not the best candidate for Phase 1 implementation, when public support is paramount to the continued success of an ITS program.

Ramp metering limits the volume of traffic entering the freeway, which can reduce freeway congestion and increase safety. To reduce congestion on the freeway, the metering rate must be set so that the total downstream demand is less than the downstream capacity. This implies that the metering rate will be less than the demand on the ramp and some ramp traffic will be delayed or diverted to an alternate route. An extreme form of ramp metering, is, of course, ramp closure. Although ramp closure may be an effective solution if one considers only freeway operations. However, it is rarely implemented due to political considerations and equity issues.

Ramp metering generally utilizes conventional traffic signals, and either responsive or pre-timed signal control. System responsive entrance ramp metering is recommended for future consideration on congested freeways in the Grand Rapids metropolitan area. Under this strategy, a series of entrance ramps are treated as a "system", and individual traffic signal cycle metering rates are determined to provide a desired mainline level of service throughout the length covered, while minimizing entrance ramp delays and impacts on adjacent corridor arterials. All relevant mainline and ramp traffic flow and queue length data obtained from roadway detectors is analyzed by central computer. and individual metering rates are then established by an algorithm programmed into the computer.

Pre-timed ramp metering, characterized by time-clock rather than traffic responsive operation, is generally recommended as a backup in the event of a communications, central computer. or other critical equipment failure. It may also be used for interim operations on a trial basis.

A sub-strategy of ramp metering deals with the manner in which vehicles are released in each metering cycle. The following alternatives are possible:

- Single vehicle, single lane
- Multiple vehicle, single lane
- Single vehicle, dual lane
- Single vehicle lane metering with bus and/or carpool bypass lane

Single vehicle, single lane metering allows one vehicle at a time to be released in each signal cycle. This is the most common metering form used, providing maximum capacity of about 900 vehicles per hour (vph).

In multiple vehicle metering (also referred to as "platoon metering"), the green phase time is extended to permit additional vehicles to pass through per cycle. Higher overall metering rates are possible with this approach (about 1,100 vph), but greater merging friction and higher accident potential are the disadvantages. Accordingly, platoon metering is not recommended.

Single vehicle dual lane metering can provide metering rates comparable to or higher than those of platoon metering, however, the ramp geometry must accommodate two lanes approaching the metering signal. Vehicles may be released simultaneously or in a staggered mode (one from one lane, then one from the other). In either case, they must ultimately use a single lane for entry onto the freeway. One advantage of this alternative is that additional vehicular storage capacity is provided.

An additional form of ramp entry control consists of metering in one lane while providing a second unmetered bypass lane for buses and/or carpools in order to give priority to high occupancy vehicles.

Because ramp metering imposes delay on vehicles wishing to enter the freeway, this disbenefit must be outweighed by the time savings and accident reduction for main lane freeway travel. Depending on travel characteristics, benefits due to ramp metering may be substantial. Data from Minneapolis, Minnesota indicate a capacity increase from 1800 to 2200 vehicles per lane per hour (vplph), and an increase in average speed from 34 mph to 46 mph.[1]

However, ramp metering is not always an appropriate response to freeway congestion. Public opposition to ramp metering is often intense. An educational campaign should be launched not only to educate the public about the benefits of ramp metering, but also to educate them regarding its use.

[1] Freeway operations Meeting Minutes. January 1994 as stated in *Assessment of ITS Benefits, Early Results,* Federal Highway Administration, August 1995.

Ramp metering must also be closely coordinated with arterial signal timing to assure that arterial operation is not unduly affected.

The *Manual on Uniform Traffic Control Devices*, (MUTCD) provides additional guidelines for the successful application of ramp control. The MUTCD notes that the installation of ramp control signals should be proceeded by an engineering analysis of physical and traffic conditions on the affected freeway, ramps, ramp connections and surface streets.

Operations Plan

The key to success of the Grand Rapids freeway management system will be an effective program of operations and maintenance. This will require personnel located at the Traffic Operations Center (TOC), individuals responsible for field maintenance, and a management structure to coordinate and administer the overall operation. Training of staff, both initially and on a continuing basis as new equipment and functions are added, is critical to insure that the staff can provide maximum effectiveness. Complete and thorough system documentation is also necessary for effective operation. This section presents a review of actions and issues related to the operation and implementation of the future system. Procurement methods, staffing, TOC sizing, system start-up plan requirements, and operations plan requirements are also addressed.

Agreements and Memorandums of Understanding

In order to be effective, the proposed freeway management system must be conceived and operated in a cooperative effort by multiple municipal agencies. Generally, its purpose is to be responsive to traffic and incident conditions without regard to jurisdictional boundaries. The system will be designed as a unit, but it must operate in the context of decentralized functions and responsibilities. Since it will support and enhance current functions, the cooperative relationships established for its operation wil! extend beyond its functions of incident detection, incident response, and motorist information. The system will serve as an effective catalyst to communication among agencies involved in incident response.

A series of agreements and memoranda of understanding will be necessary to establish and support the freeway management system. These will need to be developed over a period of time as an ordinary part of system design and development. Multiple agreements or memoranda are advisable in lieu of a single document to provide flexibility for responding to future needs.

Potential needs for cooperative agreements or memoranda of understanding would likely include four categories; agency support, system design, construction, operations, and maintenance, emergency response, and specialized control plans.

Agency Support

One of the first documents to be executed should be a joint statement of support for improved incident management systems and operations within the metropolitan Grand Rapids area. This should be a statement of policy, with specific roles and responsibilities to be identified in follow-up documents. This agreement should provide a statement of goals and objectives in support of a cooperative policy. The agency support statement should be signed by the involved state, county and city authorities. This document will serve to inform the public of intent and commitment to the system, and will provide general guidance (through goals, objectives, and policies) for further system development.

To best serve its intended purpose, execution of the agency support agreement should be well publicized. This could include signing ceremonies by county, city and state officials and may include media coverage. In addition to indicating support and cooperation of involved jurisdictions, this will provide an early opportunity for public education regarding the character and intent of the system.

System Design, Construction, Operations, and Maintenance

Agreements will be necessary among participating jurisdictions and agencies to establish and operate the system. These will address the following categories: funding, system operation and maintenance, and functional roles and responsibilities. Among the topics which may need to be addressed for each category are the following:

- Funding
  - Engineering
  - Construction
  - Start-up
  - Operations
  - Maintenance

- System Operation and Maintenance
  - Traffic operations center
  - Field equipment
  - Administration and management
  - Staffing

- Functional Roles and Responsibilities
  - Communication responsibilities of traffic operations center
  - On site coordination (incident manager, call for tow trucks, etc.)
  - Roles and limitations of service patrols
  - Identification and management of diversion route systems
  - Operation of variable message signs and motorist information systems
  - Data links (CCTV, traffic counts, operating speeds, etc.)

Emergency Response

Agreements, legislation, and cooperative understandings should be developed for the coordination of incident response. Activities toward this end are currently underway with the creation of the Incident Management Task Force and the publishing of the Incident Management Plan for the US-131 corridor. Changes may be needed as emergency response personnel interact within the TOC and as the system design evolves, but, the system will not supplant or modify most established relationships.

Some potential new emergency response policies may require enabling legislation, including:

- Vehicle removal policies
- Lane closure policies
- Tow truck notification policies

Specialized Control Plans

In addition to agreements and/or memoranda of understanding for day-to-day system operations and emergency response, it may be useful to establish roles, responsibilities, and relationships for special conditions. These include the following, as a minimum:

- Recurring special events, such as a Griffins game
- Unique special events, such as a presidential visit
- Maintenance of traffic during construction
- Special incidents, such as hazardous material spills

Hours of Operation

Although some municipalities have provided for 24 hour weekday operation, it is possible to initiate surveillance on a more limited basis. Experience from other freeway management systems indicates that, at a minimum, the TOC needs to be staffed from the beginning of the morning rush hour to the end of the evening rush hour. One alternative would be 13 hour (generally 6:00 am to 7:00 p.m.) operation. Weekend staffing may not occur initially, but eventually it may be needed, especially during special events or adverse weather.

Two different strategies for providing staff have been utilized by different agencies: utilizing agency personnel (either existing or new hires), and contracting to a private organization to provide the personnel. In either case, the budgetary impact is essentially identical, although the specific budgetary categories may be different. As such, there is no distinction as to which approach is used.

During mid-day hours, when traffic is lighter, the operational staff can utilize some of their time to perform other activities that can be handled from within the control room. But the operator is still required to be immediately available to monitor and coordinate response to an incident which might occur.

One major advantage to locating the TOC in the proposed State Police Headquarters is that it will be monitored 24 hours a day by the State Police staff. However, if a major incident occurs during non-peak hours. the regular staff should be called in as necessary.

TOC Operators

The specific functions that the operator needs to perform include:

- Utilizing the computer displays and CCTV screens to monitor and verify the traffic conditions and incidents on the freeways.
- Operating the computer systems to select different displays and to control field devices, such as VMS's and CCTV cameras.
- Responding, via remote computer, to status and alarm messages generated when incidents are detected or equipment malfunctions are detected.
- Utilizing telephone and radio equipment to communicate with police, fire, and other personnel responding to an incident.
- Utilizing telephone or FAX equipment to communicate with media and the public regarding the status of an incident or current traffic conditions. This function may also be automated through the central information server, and/or through the provision of information via highway advisory telephone or the Internet.

- Operating recording equipment, such as a VCR, that would be utilized to capture the specifics of a particular incident.
- Troubleshooting and performing simple replacements for malfunctioning equipment in the TOC.
- Maintaining logs and other required records of activities.

Several different strategies, alternatives to the more traditional full-time agency technical or support staff, have been utilized by other TOC's for hiring operators. These include hiring college students working part-time and hiring disabled individuals on either a part-time or full-time basis. If additional operators are needed during the peak periods, part-time employment may be a logical option.

It is estimated that the TOC will require one (1) manager, two (2) operators and a part-time secretary/clerk for the Initial and Short Term Plans, two (2) additional operators for both the Medium Term Plan, and the addition of an assistant manager for the Long Term Plan. Ultimately there will be one (1) manager, one (1) assistant manger, four (4) operators and a part-time secretary/clerk.

Equipment Maintenance

The maintenance and repair of all equipment must be accomplished in a timely fashion in order to achieve effective system operation. The typical goal for these systems is a four hour response time from the time a failure is reported until the equipment is returned to service. This requires a maintenance technician with adequate spares, appropriate tools and equipment, and up-to-date training.

It is estimated that the system will need one (1) maintenance person for the Initial Plan, with one (1) additional person for the Short Term Plan, and one (1) additional person for the Long Term Plan (3 total for all phases).

It is recommended that at least one technician be dedicated to ITS equipment. While it is possible to share this individual with other maintenance and support activities, it is important that the technician's first priority be the support of the field equipment. This individual should be available prior to the start of any construction for the project to allow familiarity with the system design. The technician's input to the design process, to insure that maintainability is built into the system, will yield long-term benefits. The technician should serve as the field inspector during all construction work so that details are retained by an agency employee. Also, since the technician will have to live with or correct any problems created by the construction, there will be a strong incentive to get the system built correctly.

Another important role of the maintenance technician is to coordinate with other roadway maintenance or construction activities to minimize the disruption of field equipment. Because contractors and other organizations do not always recognize the importance of the field equipment and associated power and communications circuits. Inadvertent actions can create problems. The maintenance technician, by being available or on-site during these potential disruptions, can minimize or eliminate equipment down-time.

The maintenance technician needs to be well experienced in a wide range of skills, including electronics, communications, power distribution, cable installation and repair, portable generators, and general small scale mechanical repairs. Since the maintenance technician will be faced with diverse equipment and failure conditions, a broad set of general repair capabilities is required. Effective troubleshooting and problem isolation techniques, supported by a systematic and logical approach, is needed to quickly identify and correct problems. Preventive maintenance, locating and repairing small problems before they become major, and conscientious record keeping and documentation are also regular components of the equipment maintenance program.

System Management

A manager of the operators and maintenance technician will be required. It is desirable that this individual also have an engineering background so that broader system support and long-range upgrades can be handled. The role of the manager is to provide day-to-day supervision and scheduling of operations and maintenance activities, to coordinate with other agencies and organizations, to develop plans and policies for incident management and freeway monitoring, and to financially manage the operation by developing budgets and being responsible for operating within these budgets.

The manager will also be available to support the operator during a major incident, to be a higher level liaison with other agencies and the media, and to supervise a back-up person if regular operations personnel are not available. The manager will be responsible for training new operations personnel, and insuring that current staff are trained on new equipment and that refresher training is conducted for all personnel, as necessary.

The manager will be responsible for supervision of maintenance activities, insuring that adequate spares are available and that the maintenance technician has all the tools, equipment, and test devices needed to perform effectively. The manager must make certain that the technician's training is current and up-to-date. When a crises occurs, the manager must expedite support and repair services, and provide a buffer between the maintenance technician and other individuals, so that the technician can work without being disturbed. As the system evolves into the Full System, an Assistant System Manager will be required to support the management and operation of the TOC. The Assistant System Manager should have similar qualifications to the System Manager. The Assistant should work the shift opposite the System Manager to provide management of the TOC while the System Manager is not present

Support staff, such as secretarial, clerical and receptionist personnel, can be provided on a shared basis from the existing organization where the TOC will be located. The freeway management system and TOC do not require dedicated personnel. A part-time equivalent should be included in the budget to account for this labor component.

Implementation Plan

Part 655.409 of Title 23 Code of Federal Regulations requires the development of an Implementation Plan prior to the deployment of surveillance and control elements of an incident management plan. According to current guidelines, the Implementation Plan is to be completed prior to project design completion and must be approved by the Federal Highway Administration (FHWA) prior to authorization of construction funding. The Implementation Plan will need to finalize needed legislation, system design, procurement methods, construction management procedures, acceptance testing, and system start-up. It will also need to include an Operations Plan and Maintenance Plan which provides specific information regarding the equipment to be installed. The intent of the Operations Plan is to clearly describe all significant system features and the means for installing and operating the system. An important element of the Operations Plan is the commitment of involved agencies to staff the system and fund its operation. Many of these issues must await design activities in order to provide an appropriate level of detail.

Traffic Operations Center Concept

The Traffic Operations Center will serve as the centerpiece of the Grand Rapids freeway management system. Most ITS functions will be performed at the TOC. Both technically and visually, the TOC will play a major role in defining the success and public image of the Grand Rapids system.

The internal functions of the TOC will include items such as incident management, systems operations, freeway and arterial monitoring, congestion management, and other ITS activities. Important to the success of the internal operations of the TOC is the facilities (the building, grounds, utilities, etc.) and location. Adequate floor space, highway access, communication linkage, site security, building construction, and alternate route access all contribute to a successful TOC.

Although the proposed Michigan State Police District 6 headquarters has been identified as a possible final location for the TOC for the entire metropolitan region, it is worthwhile to iterate the factors that should be considered when locating a TOC. If, for any reason, MDOT needs to find another location for the TOC, potential sites should be evaluated with respect to these factors.

- *Ownership* - Ownership of the property is an important factor. Whether the property is owned or leased has significant implications in terms of on-going expenses (such as rent) and stability, which would be affected by the lease term.
- *Space Availability* - Space availability refers to the amount of space available for the TOC. This is given in square feet for existing structures, and acreage for vacant lots.
- *Highway Access*- Highway access indicates distance to the nearest access to the highway system, such as Route 131.
- *Alternate Access for Emergencies* - Alternate access lists alternate routes from the site to the highway system. These routes are in addition to those listed in the highway access category.
- *Costs* - Costs include all items necessary to prepare the site for the installation of the TOC. Included within this would be items such as building construction or renovation, utility connections/installations. communication links, property acquisition, etc.
- *Communication Link Potential* - This category reflects proximity to fiber optic networks, microwave towers, telephone lines, types of telephone lines, cellular phone usage, short range microwave capabilities, etc. Proximity to the interstate is especially important when one considers the need to connect to the fiber optics communication infrastructure.
- *Site Utilities* - Site utilities include existence or availability of utilities such as electricity, sewer, HVAC, gas, and water.
- *Site Security* - Site Security includes items such as fences, barriers and adjacent types of development.

A generic conceptual plan for a 6,000 sq. ft. Traffic Operations Center is presented on Figure 7-6. This layout assumes that the traffic operations center is co-located with another facility, such as the proposed State Police District 6 Headquarters. Functions that are assumed to be located elsewhere in the facility include:

- Emergency generator, load bank, and fuel tank.
- Transformers, main building electrical room.
- Building HVAC equipment.
- Condenser, radiator or chiller for computer/communications room air handling units.
- Restrooms.
- Employee lounge or lunchroom.
- Main reception area.
- Multi-purpose space.

The control room has space for up to five or six traffic operations and/or communications positions. Control of the system will be performed by the operators at workstations which will provide full access to all system components. The control room will also house monitors for the CCTV system and a video wall that may be used for both graphics display and viewing of CCTV images. The viewing, operations and electronics areas will be on raised flooring to accommodate air distribution and cable routing. The layout also provides space for maintenance of the field equipment. Two open staff cubicles could be used by either operators or response personnel. This scheme is laid out with a general building circulation corridor bisecting the TOC.

This scheme is generic in nature and no provisions have been made for accommodating specific facility requirements such as configuration of space available, building circulation patterns and exiting requirements, exterior windows. views, and glare, adjacencies of other building functions, or building structure, mechanical and electrical systems.

INTERAGENCY COORDINATION

Agency Roles And Responsibilities

The following is a description of the future roles and responsibilities of the agencies participating in establishing a freeway management system for the Grand Rapids area:

Michigan Department of Transportation (MDOT)

MDOT will oversee the development and operation of a traffic operation center (TOC) which will be the focal point for the freeway management system and the distribution of current traffic information. This system will eventually serve the entire interstate network and selected freeway facilities in the Grand Rapids metropolitan area, and will consist of the following:

- Control of all field equipment on the interstates and freeways in the system.
- Equipment, primarily covering the interstate and freeway network, includes a variable message sign (VMS) system, a traffic detection system, a closed circuit television (CCTV) surveillance system, and a highway advisory radio system (HAR).
- A traveler information kiosk system in key generators in the area, highway advisory telephone (HAT), and an electronic bulletin board system for access by citizens and businesses in the area may be incorporated in the future.
- Other future systems, not justified by existing traffic conditions, may include a freeway ramp metering system and freeway high occupancy vehicle (HOV) facilities. The need for these facilities should be continually evaluated over time.
- A direct connection should be provided between the TOC and the City of Grand Rapids Traffic Signal System. This would allow for the exchange of traffic data and system status information between the two systems. Consideration may be given to allowing the TOC to implement diversion route timing plans during hours that the City Traffic Signal System is not manned. Agreements and memorandums of understanding would have to be established describing the conditions under which control would be warranted and permitted.
- The activities of motorist assistance patrols should be coordinated with the TOC to help in the removal of disabled vehicles associated with minor incidents and disabled vehicles.

The previously mentioned systems should be operated and maintained by MDOT, either directly through increased staffing and training for employees, or through a contract with an outside company or agency for the provision of the needed services. If the TOC is ultimately located at the State Police offices, MDOT may wish to contract with the State Police for operations of the TOC.

Local Jurisdictions/Public Works Departments

Each arterial used for a freeway diversion plan should have a signal control system capable of adapting to accommodate the additional demand that would be expected. This may consist of solid state controllers with remote control for the implementation of a variety of pre-determined timing plans, including those appropriate for the implementation of a freeway diversion scheme. An alternative would be the use of adaptive signal control systems, which would automatically detect the increase in demand on the diversion route, and increase capacity as needed. Coordination with the TOC will depend on the method by which signal timing plans are changed, as well as the agreements between the TOC and the city. Ideally, coordination and communication would consist of the following factors.

- Although the City of Grand Rapids will maintain primary control of operations of the signal systems, timing plans to absorb the additional demand resulting from freeway diversion will be implemented by the city upon the recommendation of the TOC, by the TOC during off-hours, or automatically implemented via adaptive signal control.

- Local jurisdictions will have access to current traffic conditions, including CCTV and additional data as needed, on the freeway facilities in their jurisdiction. Local jurisdictions will be responsible for obtaining the funding and equipment necessary to access this information.

- MDOT should retain primary control of the CCTV cameras on the interstates and freeways. Communications can be established for local agencies to view the CCTV camera images of facilities in their jurisdiction at any time. Local jurisdictions should be able to request selection and movement of the CCTV cameras in their jurisdiction. Requests should be granted by operators at the TOC when possible. It would also be possible to implement CCTV cameras that could be controlled from multiple locations (by local jurisdictions and the TOC). Under this scenario, the TOC would have primary control, and the TOC commands would override the local commands.

- CCTV’s located on arterial streets will be controlled by the agency responsible for implementing and operating such cameras, although the images should be available to both local jurisdictions and the TOC.

Law Enforcement

The state and local police should coordinate and communicate with the TOC when responding to incidents on the freeway system. This includes not only response by law enforcement officers, but also the response of the Motorist Assistance Patrol.

- Local and state police should not have direct control of the operations of the freeway/expressway or traffic signal equipment unless the Michigan State Police assumes operations of the TOC.

- Local and state police should have access to CCTV camera images in their jurisdiction and should be able to request selection and movement of the CCTV cameras. The police desk should be able to view the freeway and arterial status traffic information displays. Law enforcement agencies will be responsible for obtaining the funding and equipment necessary to access this information.

- The TOC will communicate with law enforcement by either telephone or two-way radio.

Public Transportation

The local transit agency, GRATA, should coordinate and communicate on an as-needed basis with the TOC.

- GRATA should be able to access current traffic information and any other information that would be valuable for their operations. GRATA will be responsible for obtaining the funding and equipment necessary to access this information. Transit agencies may use this information to re-route transit vehicles around congested areas.
- Should GRATA implement an automatic vehicle location (AVL) system, this information should be made available to the TOC. The agencies operating the TOC will be responsible for obtaining the funding and equipment necessary to access this information.
- Any freeway HOV facilities developed in the future should be developed in coordination with transit service providers, as well as arterial HOV facilities.

Emergency Response and Coordination

The TOC should utilize the existing 911 system for direct contact with emergency responders in the case of an accident on the freeway. The system should be set up so that the TOC operator will be automatically connected with the appropriate agency upon identification of the location of the incident and the kind of emergency response agency needed.

- The existing 911 system will be maintained as the primary mechanism for responding to emergencies on the freeways.
- The TOC should use two-way radio for communication with emergency responders for on-going coordination once the incident response has been initiated.
- A special number for reporting non-emergency incidents on the freeway should be implemented. This number would be answered by personnel at the TOC, who could then coordinate with the Motorist Assistance Patrol, or other appropriate agencies, as needed. Implementation of a system such as this one. which requires motorists to make a determination as to the severity of the incident (for example, vehicle disablement versus injury accident) would require significant public education activities.

Private Sector Involvement

Wherever possible, the private sector should be involved in developing and expanding the advanced freeway management system and the distribution of traveler information.

- Private sector should include, but not be limited to, universities and colleges, manufacturing and service companies, the broadcast and print media, and communications and entertainment companies.
- Other opportunities for private sector participation might include information kiosks, new products testing, and the development of an area wide communications network.
- Information from the TOC should be available to traffic reporting agencies and cellular phone companies.
- Opportunities for public/private ventures should continue to be explored. Additional aspects related to public/private activities for the provision of traveler information are discussed later in ***Funding hues.***

Implementation Issues

Maintenance Issues

Agencies participating in the freeway management system should develop clear guidelines on the maintenance of the elements of the system. The foIlowing are beginning elements of assigning responsibilities for maintenance:

- The state should be responsible for the maintenance of the field equipment.
- Local jurisdictions and agencies should be responsible for maintenance of equipment they have purchased for communications and for obtaining information from the TOC.
- CCTV cameras and detection placed by the TOC on arterial streets that are primary diversion routes should be maintained by the TOC unless other agreements are made with the local jurisdiction.
- Space at the TOC should be reserved for maintaining, testing and troubleshooting. This space can be either on-site or off-site.

Operations Issues

Agencies participating in the freeway management system should develop clear guidelines on the operations of the system. These responsibilities should evolve from the following initial principles of operation including:

- Compatibility with TOC software and operations should be considered during selection of new signal system equipment on arterials that may be used as freeway diversion routes.
- An agreements between MDOT and the City of Grand Rapids for the operations of signal systems and other equipment on arterial facilities needs to be developed. All operating agreements should be formalized and written, whether the work is done in-house at public agencies or by contract with private firms.

Open Issues

There are several issues that will need to be continually explored as new information becomes available and as technology and circumstances change. These issues include

- Roles for the private sector.
- Funding sources, which vary depending on the kind of expenditure, the agency requesting funds, and changes in legislation and available funding.
- Level of implementation, which will affect the number and variety of affected agencies.
- "Open architecture", which is still being defined at the national level and which should be a significant consideration with respect to integration with in-vehicle navigation systems in the future.
- The need to modify the system to incorporate new technologies.

FUNDING ISSUES

ITS projects are of such diverse scope that many unique combinations of existing Federal, state, local, and private financing opportunities are available to help build and operate these systems. The following sections highlight a number of specific and proven public and private sources that can be utilized as part of a creative financing package for ITS implementation and operation. This includes actual dollars such as public funding via the Inter-modal Surface Transportation Efficiency Act of 199 1; the National Highway System Designation Act of 1995; various state and local user-fee options; in-kind services, such as trading of a portion of agency-controlled right-of-way to a communication company that wishes to install fiber-optic cables in exchange for that agency's right to use a pre-defined amount of fiber-optic bandwidth for either no fee or a significantly reduced fee;, and innovative techniques for financing operating costs, such as the ability of an agency to sell their raw traffic information to value-added service providers who specialize in converting this raw data into valuable information for later re-selling to the public by the value-added service provider.

Federal/State Sources

Formal Programs

With the passage of ISTEA and the National Highway System Designation Act of 1995 (NHSDA), ITS project costs, generally including those costs related to both capital and operational expenses, are now eligible for 80% Federal funding under the National Highway System program (NHS), the Surface Transportation Program (STP), and the Congestion Mitigation Air Quality program (CMAQ) portions of the above legislations. In addition: limited funding is also available under the ITS Corridors Program and the Other ITS Activities section of ISTEA. It must be noted, though, that all projects wishing to be considered for funding under any of these programs must compete for limited program dollars with other eligible projects such as non-ITS projects for the NHS, STP. and CMAQ categories. The programs also must be approved by the appropriate committee(s) in each region for inclusion in a formal three-year Transportation Improvement Plan (TIP) for the metropolitan area.

The following sections highlight key features of the above programs, detail eligible routes, and describe any special provisions that may apply to each of them. Table 7-l summarizes this information as it relates to the length of availability of operating funds, and any time limits as to when projects must be financially obligated after the funds are made available. Finally, as amended by the NHSDA in Section 101(a) of title 23, United States Code, "The term 'operating costs for traffic monitoring, management, and control' includes labor costs, administrative costs, costs of utilities and rent, and other costs associated with the continuous operation of traffic control, such as integrated traffic control systems, incident management programs, and traffic control centers". In other words, the operating costs for intelligent transportation systems, as defined in the legislation, can be covered under NHSDA funds.

National Highway System (NHS) Program

Established in Title I-A, Section 1006(a) of ISTEA, and officially designated in Title I, Section 101(a) of the National Highway System Designation Act of 1995, the National Highway System (NHS) consists of major roads in the United States, including all Interstate routes, a large percentage of urban and rural principal arterials, the defense strategic highway network, and strategic highway connectors (see Table 7-2 for specific NHS-designated routes within the Grand Rapids metropolitan area). All routes on the NHS are eligible to use these funds for "Capital and operating costs for traffic monitoring, and control management, facilities and programs" [Section 103(i) of title 23, United States Code, as amended by Section 30 1 (a) of title III, NHSDA].

There are no limitations as to the number of years that NHS operating assistance may be obtained for any given project (Section 301(a) of title III, NHSDA eliminated ISTEA's "startup costs" language that had limited operating assistance funding to a maximum of two-years). However, all requests for NHS operating assistance must be approved for placement in a region's formal TIP each year.

Surface Transportation Program (STP)

Established in Title I-A, Section 1007(a) of ISTEA, the Surface Transportation Program (STP) is a block grant type program that may be used by states and localities for eligible projects on any roads, including those on the NHS, that are not functionally classified as either local or rural minor collectors. Projects on all STP-eligible routes may use these funds for 'Capital and operating costs for traffic monitoring, management, and control facilities and programs" [Section 1007(b-6) of title I-A, ISTEA].

There are no limitations as to the number of years that STP operating assistance may be obtained for any given project. However, all requests for STP operating assistance must be approved for placement in a region's formal Transportation Improvement Plan (TIP) each year.

Table 7-l. Federal Funding Sources for ITS Capital and Operating Costs

Program Name	Eligibility Details		
	Routes/Areas	Capital costs	Operating costs
National Highway System (NHS) program	All Interstate routes, most urban & rural principal arterials, and the defense strategic highway network & connectors	YES	YES (for unlimited number of years if annually placed **in** an area's formal TIP)
Surface Transportation Program (STP)	All public roads (including NHS routes) except those classified as local or rural minor collectors	YES	YES (for unlimited number of years if annually placed in an area's formal TIP)
Congestion-Mitigation Air-Quality (CMAQ) program	Public roads in areas the Clean Air Act designated as being in non-attainment for ozone and carbon monoxide as of Federal fiscal year 1994	YES	YES (typically limited to three-years or as long as FHWA/EPA deem operations funding for a particular ITS project helps air quality)
ITS Corridors program	Funding primarily for use in up to ten corridors specifically designated by the USDOT. Limited "left-over" funds may be available for other areas	YES*	YES* (no specific limitations)
Other ITS Activities section of IVHS Act of 1991	Nationally-competitive funding for specific ITS projects. Has traditionally been used to fund "operational field tests" and other "early deployments"	YES*	YES* (no specific limitations)

All funds made available to states under the ITS Corridors program and the Other ITS Activities section of ISTEA require dollars to be obligated to specific projects within one year after the fiscal year in which they are made available or be sent back to Washington, D.C. for re-allocation to other states for use on their ITS projects.

Table 7-2 Designated NHS Routes in the Grand Rapids Metropolitan Area

Route Number (Road Name)	From	To
I-96	Entire Length	
I-196	Entire Length	
I-296	Entire Length	
I-196 Business Route	US-31 I-l 96 (Kent Co.- City of Grand Rapids)	I-196 (Ottawa Co. - City of Holland) Hall Street
US-31	South of Southern Ottawa County Line	North of Northern Ottawa County Line
US-131	South of Southern Kent County Line	I-196
	North Junction of I-296	North of Northern Kent County Line
US-31 Business Route	South of Southern Ottawa County Line	US-31 (Ottawa Co. - City of Holland)
US-131 Business Route	Southern Junction of US-131 (Kent Co.- City of Grand Rapids)	Northern Junction of US-131 (Kent Co. - City of Grand Rapids)
M-8 (proposed) (South Beltline)	I-196	I-96
M-11 (Wilson Avenue)	I-96	I-196
M-11 (28th Street)	I-196	I-96
M-21	I-96	East to the Grand River
M-37 (East Beltline)	Southern City of Kentwood Line [i.e M-8 (Prop. South Beltline)]	I-96
M-37 (East Beltline)		
M-40	Southern Ottawa County Line	US-31 Business Route (Ottawa Co. – City of Holland)
M-44 (Northeast Beltline)	Junction of I-96 / M-37	North to the Grand River
M-45	M-11	US- 131 Business Route (Kent Co.– City of Grand Rapids)
M-104	US-31	Westbound I-96 (Ottawa Co. - City of Gr. Haven)
Patterson Street	44th Street	M-11 (28th Street)
44th Street	M-37 (East Beltline)	Patterson Street

Congestion Mitigation Air Quality (CMAQ) Program

Established in Title I-A, Section 1008(a) of ISTEA, the Congestion Mitigation Air Quality program (CMAQ) directs funds toward transportation projects in areas that were designated under the Clean Air Act (CAA) as being in non-attainment for maximum allowable levels of ozone or carbon monoxide pollutants during Federal fiscal year 1994 (see Table 7-3 for more details regarding the Grand Rapids Metropolitan area), and are either still in non-attainment status or were later redesignated by the Administrator of the Environmental Protection Agency (EPA) as being in attainment and therefore subject to maintenance requirements for ambient air quality standards. All public roads within CMAQ-eligible areas, including roads within the Grand Rapids metropolitan area, may use these funds “to establish or operate a traffic monitoring, management, and control facility or program if the [United States] Secretary [of Transportation], after consultation with the Administrator of the Environmental Protection Agency, determines that the facility or program is likely to contribute to the attainment of a national ambient air quality standard” [Section 319(b-4) of title III, NHSDA].

Table 7-3. Clean Air Act Attainment Status for the Grand Rapids Metropolitan Area

POLLUTANT CATEGORY	COMPLIANCE STATUS	NOTES
Ozone (03)	Non-Attainment	Pending reclassification as a “Maintenance Area” due to the fact that most of the pollution is coming across Lake Michigan from Indiana and Illinois.
Carbon Monoxide (CO)	Attainment	
Particulate Matter of Size 10 Microns or Less (PM- 10)	Attainment	
Nitrous Oxides (NOx)	Attainment	
Sulfur Dioxide (SO_2)	Attainment	
Lead (Pb)	Attainment	

Neither ISTEA or NHSDA specifically limits the number of years that operating assistance may be obtained for any given project. However, the FHWA’s latest CMAQ guidance issued on July 13, 1995 places a typical three-year limitation on CMAQ reimbursements of ITS “start-up” or operations costs. Furthermore, it says “If at some point the FHWA, in consultation with EPA, determines the operation of these new improvements are no longer contributing to continuing improvements in air quality, further operating costs will become ineligible for CMAQ funds”.

ITS Corridors Program

Established in Title VI-B, Section 6056(a) of ISTEA, the ITS Corridors Program is primarily used to finance ITS projects on “not less than three but not more than ten corridors” [ISTEA Title VI-B, Section 6056(b)] that have been specifically designated by the Federal Highway Administration (FHWA) due to their having characteristics such as severe traffic density (i.e. at least 1.5 times the national average for such class of highway), extreme non-attainment for ozone, and significant complexity of traffic patterns, etc. However, any limited left-over funding from these specific corridors may be “...allocated to eligible State and local entities for application of intelligent vehicle-highway systems in corridors and areas where the application of such systems and associated technologies will make a potential contribution to the implementation of the [USDOT] Secretary’s plan for the intelligent vehicle-highway systems program . . . and demonstrate benefits related to...improved operational efficiency, reduced regulatory burden, improved commercial productivity, improved safety, [and/or] enhanced motorist and traveler performance” [ISTEA, Title VI-B, Section 6056(c)].

No specific stipulations are given that may limit the use of these funds to capital projects vs. their use as operational assistance. However, it must be noted that all funds made available to states under the ITS Corridors program require dollars to be obligated to specific projects within one year after the Federal fiscal year in which they were made available to a state, or be subject to being sent back to Washington, D.C. for re-allocation to other states for use on their ITS projects [NHSDA. Title III, Section 338(b)]. This is a key difference as compared to the NHS, STP, and CMAQ programs, in which states have up to three years after the year in which these block-grant dollars are made available to them before they are lost if not obligated to specific projects [Title 23, United States Code]. In all cases, though, the FHWA recommends that projects must be ready to be advertised for bidding for construction within a “reasonable” period of time, which is typically three-months to one-year once they have been obligated after appropriate programming into a State’s Transportation Improvement Program (STIP).

Other ITS Activities Program

Established in Title VI-B, Section 6058(b) of ISTEA, the Other ITS Activities section of the IVHS Act of 199 1 is a nationally-competitive funding source for specific ITS projects that the United States Department of Transportation (USDOT) wishes to promote. These dollars have traditionally been used to fund “operational field tests” and other “early deployments” of ITS technologies.

No specific stipulations are given that may limit the use of these funds to capita! projects vs. their use as operational assistance. However, it must be noted that all funds made available to states under the Other ITS Activities section of the IVHS Act of 1991 require dollars to be obligated to specific projects within one year after the Federal fiscal year in which they were made available to a state, or be subject to being sent back to Washington, D.C. for re-allocation to other states for use on their ITS projects [NHSDA, Title III, Section 338(b)]. This is a key difference as compared to the NHS, STP, and CMAQ programs, in which states have up to three years after the year in which these block-grant dollars are made available to them before they are lost if not obligated to specific projects [Title 23, United States Code]. In al! cases, though, the FHWA recommends that projects must be ready to be advertised for bidding for construction within a “reasonable” period of time, which is typically three-months to one-year once they have been obligated after appropriate programming into a State’s Transportation Improvement Program (STIP).

Creative Financing

In addition to the above formal programs, the NHSDA enabled two new financing mechanisms that may be utilized by state and local governments to further leverage these Federal dollars: (1) Flexible matching funds, and (2) State infrastructure banks.

Flexible Matching Funds

A provision in Title III, Section 322 of the NHSDA allows private funds, materials, or services to be donated to specific Federal-aid projects, and permits a state to apply the fair market value of these donations towards the amount of matching funds that need to be provided for projects in which costs are shared with the Federal government. Since ITS projects can often involve unique public/private partnerships for capital and/or operating expenditures, as discussed later, this provision can be especially valuable for implementing ITS projects. This is especially true when an agency has limited funds on hand to match Federal dollars or when an agency has enough funds on hand to match Federal dollars but they wish to leverage additional Federal dollars so that the scope of a project may be expanded without expending any additional state/local matching dollars.

State Infrastructure Banks (SIB)

A provision in Title III, Section 350 of the NHSDA allows the Secretary of Transportation to enter into agreements with a maximum of ten states to establish what will be known as State Infrastructure Banks (SIB). A SIB is an infrastructure investment fund that can be created at the state or regional level to make project loans to help finance eligible highway construction[2] and transit capital projects. As such, Federal funds contributed to the SIB cannot be used for traditional grants. In addition, because it is designed to complement the regular Federal-aid program, no new funds were made available to capitalize or administer this program. However, states may contribute up to 10% of several categories of their Federal-aid highway and Federal transit funds to capitalize their bank. A SIB can also "provide credit enhancements, serve as a capital reserve for bond or debt instrument financing, subsidize interest rates, ensure the issuance of letters of credit and credit instruments, finance purchase and lease agreements with respect to transit projects, provide bond or debt financing instrument security, and provide other forms of debt financing and methods of leveraging funds that are approved by the [United States] Secretary [of Transportation] and that relate to the project with respect to which such assistance is being provided" [Section 350(1-3) of title III, NHSDA]. Furthermore, a SIB established under this program may provide this above-described assistance to public or private entities in an amount equal to all or part of the cost of carrying out a SIB-eligible project [Section 350(c) of title III, NHSDA]. Finally, it must be emphasized that even though specific details regarding how this process will actually work are not yet available since USDOT rules and guidelines are still forthcoming, there is much potential for using SIB's in ITS-related capital projects because these projects can often have a future identifiable revenue stream (see Sections 1.3 and 1.4, below). However, since the United States Secretary of Transportation must report the results of this SIB pilot program to Congress by March 1, 1997, only time will tell if this initiative will truly yield its intended results.

State/Local Sources

Transportation User Fees

Although some state governments, including Michigan, have recently found it difficult to increase their state gas tax, it should be carefully examined by local officials for possible implementation on a regional basis for the funding of ITS projects since it is a direct user-paid revenue option that can raise relatively large sums of money with low administrative costs, especially if the state will collect the tax and return local revenues to the local government. FHWA estimates that urban areas consume about 400 gallons of fuel per person per year. A one-cent regional motor fuel tax in an area with a population of 100,000 could raise $400,000 per year, while only costing the average driver $4 per year. If a one-cent regional motor fuel tax were implemented in the Grand Rapids metropolitan area (1990 US Census population of 688,000), as much as $2.75 million dollars could be raised each year. Furthermore, even if this potential revenue amount was calculated based only on those in the 18 to 64 year-old age group (1990 US Census group of 419,000 persons), almost $1.7 million dollars could be raised each year. However, state legislation may be needed before a local government could levy any such motor-fuel tax.

Billboard Fees

Some transportation financiers have suggested a "user fee" for off-premise billboard advertising. The logic behind this idea is that since advertising would be useless without streets and highways, advertisers and/or sign owners could be charged a user fee based on the size of their sign and the daily traffic count of the adjoining highway. Although there are no known jurisdictions that currently impose such a fee,

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2 "The term 'construction' means the supervising, inspecting, actual building, and all expenses incidental to the construction or reconstruction of a highway, including . improvements which directly facilitate and control traffic flow, such as traffic control systems..." [23 USC Sec. 101(a), by reference in Title III, Sec. 350(1-2) of NHSDA].

it is similar to the currently accepted practice of transit properties receiving small amounts of advertising revenue from messages placed inside or outside buses and subway cars.

Public/Private Sources

Implementation of an intelligent transportation system will likely involve partnerships with private industry. businesses and the academic community. In fact, the primary providers of traffic information are currently private entities that provide radio and television traffic reports. The extent of the partnerships that will be formed depend on several things. First. the need for partnerships must be adequately communicated and understood. Understanding can be enhanced by an intensive program to explain the goals and objectives of ITS and how these goals can be enhanced through partnerships. Second. public technical assistance (for example, to enhance coordination with local jurisdictions) should be made available where possible, and its availability should be made explicit. Third, resources are limited in all sectors of society, and the benefits of participation for all affected entities should be examined and carefully delineated.

Communications Partnerships

ITS projects can require significant communication bandwidth capacities depending on the amount of data and/or video that may need to be transmitted. In addition, many telecommunications companies have specific right-of-way needs for the installation of new fiber-optic communications networks to better serve their customers' data-transmission needs. Therefore, a number of cooperative opportunities now exist that can unite private-sector needs with public-sector resources, and public-sector needs with private-sector resources. For example, public-sector resources such as significant "vacant" right-of-way strips along freeways and some major arterials can be exchanged to satisfy public-sector data/video communication bandwidth capacity needs. Similarly, private-sector resources such as extensive fiber-optic cable networks can be exchanged to satisfy private-sector needs of narrow strips of right-of-way that may be used to install conduit and additional fiber-optic cables.

Some jurisdictions are utilizing this concept with much success by trading a portion of agency-owned right-of-way to a telecommunications company that wishes to install fiber-optic cables in exchange for that agency's right to use a pre-defined amount of fiber-optic bandwidth for either no fee or a significantly reduced fee. Furthermore, additional benefits can be derived from these types of partnerships because of the ability to leverage significant amounts of additionai Federal transportation dollars now that Federal law allows private donations to be credited towards the matching funds that state/local agencies must provide for Federal-aid projects. In fact, an arrangement with TCI to provide a fiber optic backbone in conjunction with TCI's system upgrade is being pursued by MDOT and the City of Grand Rapids. However, it must be cautioned that the Michigan Department of Transportation's ability to raise significant dollars via these types of communications partnerships is unclear due to ambiguities in relevant portions of **MDOT** policy and State of Michigan law. The following two cases detail this further.

Case #l. As per the MDOT Commission's February 23, 1995 policy statement regarding *Longitudinal Use of Limited Access Right-of- Way by Utilities* (#CPl l00.l4A),

> "...occupancy of the right-of-way by utilities...will be in compliance with such special requirements...as the department may determine, including, but not limited to: (1) **A** permit from the department is required for each control section, with a permit fee of

> $1,000 per mile. A minimum total fee of $5,000 for all permits pertaining to a single utility project will be charged...".

At first appearance, this may seem to indicate that MDOT can only raise $1,000 per mile via communications partnerships. However, upon further inspection, the language "...including, *but not limited to..." (*emphasis added) seems to indicate that MDOT may, if they so desire, impose additional requirements such as the donation to MDOT of a pre-defined portion of the communications bandwidth that is proposed to be installed by the telecommunications company. Furthermore, an interpretation of precedent for additional fees may also be found in the statement "...A *minimum* total fee..." (emphasis added), which seems to indicate an intent for *at least* $1,000 per mile to be charged, rather than an intent for at most $1,000 per mile to be charged. Finally, since this is MDOT policy rather than State of Michigan law, MDOT Commissioners have the ability to rescind this policy if it actually does hinder the Department from entering into communications partnerships such as the type described above that significantly benefited the Missouri Department of Transportation.

Case #2 It has been suggested that Article 2-A of the *Michigan Telecommunications Act* (SB#722), which was signed into law on November 30, 1995 by Governor John Engler, precludes MDOT from entering into communications partnerships because it states that,

> "Any fees or assessments made under section 251 shall be on a nondiscriminatory basis and shall not exceed the fixed and variable costs to the local unit of government in granting a permit and maintaining the right-of-ways, easements, or public places used by a provider." (Section 253)

However, this above paragraph, and other similar language in this Act's section 251, specifically refers to a "*local* unit of government" (emphasis added). As such, these limitations may not be relevant to any communications partnerships that the Michigan Department of Transportation may wish to enter into along any right-of-way that is under their jurisdiction.

Value-Added Partnerships

The National Weather Service obtains needed dollars by selling their "raw" weather data to cable television's *The Weather Channel,* which repackages it into useable "information" for "re-selling" to the public through advertisements on their network. In a similar manner, some transportation agencies are obtaining needed ITS operational funds by selling their "raw" traffic data to similar "value-added" service providers who specialize in converting and repackaging this data into public-useable "information". This information is then re-sold to radio stations, TV stations and/or other interested parties such as digital paging service providers. It must be noted, though, that the legality of this type of partnering, which amounts to the government selling publicly-obtained information on a for-profit basis, has not formally been approved or disapproved by any State or Federal Attorney Generals' offices.

Early Deployment Profit Sharing

In what may at first seem to be a reverse variation of the above value-added partnerships scenario, Early Deployment Profit Sharing can be a way for public entities to accelerate the deployment of specific ITS User Services that neither the public-sector nor the private-sector may be able to do entirely on their own.

An example of this. in a city similar in size and character to Grand Rapids, is the ARTIMIS system recently deployed in Cincinnati. Ohio.

The greater Cincinnati area is currently served by *SmarTraveler,* an Advanced Traveler Information System (ATIS) operated by SmartRoute Systems[3]. This system, which went on-line in June, 1995, provides current transportation information via telephone for the metropolitan Cincinnati area within the I-275 loop, which encompasses urbanized areas in both Ohio and northern Kentucky. The information provided includes current, route specific information on traffic volumes, travel times, and alternate routes, if necessary. Schedule information on transit and airport shuttles, as well as car-pools, is also available. Calls for traveler information are free local calls; cellular calls through selected cellular providers are also free of charge. After dialing the seven digit phone number or three digit cellular number, an audio menu is provided, this allows specific information to be selected on any of 16 travel routes in the area.

Current reports about traffic conditions are provided from 6 a.m. to 7 p.m., Monday through Friday. Information regarding special events and construction activities is available 24 hours a day. The information provided is based on a variety of sources, including 15 remote-controlled CCTV cameras, two aircraft, a network of "mobile probes" (drivers who report traffic conditions by cellular phone or two-way radio), direct contact with transit agencies and shuttle services, radio contact with law enforcement and emergency responders, and direct communication with key state and local transportation agencies.

Cincinnati's *SmarTraveler* is the first phase of the Cincinnati/Northern Kentucky area's Advanced Regional Traffic Interactive Management & Information System (ARTIMIS). Funding for the system is provided primarily by the Federal Highway Administration under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Kentucky and Ohio also provide state funds for the service. The ARTIMIS system operates under the authority of the Kentucky Transportation Cabinet (KYTC), the Ohio Department of Transportation (ODOT). and the OK1 Regional Council of Governments. When fully operational in 1996, ARTIMIS will include detectors, variable message signs, area-wide highway advisory radio coverage, and freeway service patrols in addition to the *SmarTraveler* system. The total cost for ARTIMIS is approximately $35 million.

During the first 18 months of the contract, SmartRoutes built and is operating their own facility to provide ATIS for the Cincinnati area. For the remaining 21 months of the 39 month contract, SmartRoutes will operate the facilities currently being built by the Kentucky and Ohio Departments of Transportation. The public sector commits to purchase services for a specified period of time. SmartRoute Systems is also responsible for staffing and operating the center. A center such as the one in Cincinnati can be in operation within six months of the decision to implement. In some cases, negotiated agreements are entered for profit sharing with public agencies of the profits from sales of the database to private entities, such as cellular phone companies and paging companies.

The sale of information to private entities does raise the issue of equity. The philosophy generally expressed is that as long as the public has free access to the information (in this case via telephone), information can justifiably be sold to private entities.

Implementation of a TOC through a private entity should be considered in Grand Rapids. The fast implementation time, coupled with the fact that this system would relieve MDOT of staffing and operation duties (at least in the short term), makes the option quite attractive. Finally, implementation of a system such as this one would allow MDOT to gain experience in TOC operations prior to implementation and

3 Discussion of this system is based on information provided by SmartRoute Systems.

operation of their own TOC. Finally, this kind of arrangement would allow the freeway management system to be initiated prior to the construction of the Michigan State Police District 6 Headquarters.

Academic Input

The academic community may be able to play an important role as well. Academic institutions are not only employers, but are also able to undertake a role in research and training. Coordination with academic institutions, such as Michigan State University in Lansing, may include employment of student interns and participation in cooperative education programs, the provision of data for research and educational efforts, and student tours of the Traffic Operations Center. Bringing the academic community into the ITS programs can significantly broaden the approach to both the technical and institutional arrangements that are essential to the success of the program.

Coordination with area colleges and universities can be pursued. Possible activities include:

- Provision of data and video feed to regional colleges for research and educational activities.
- Research in transportation technology.
- Training in transportation fields, using teaching expertise at the colleges.
- Receiving information about transportation for use by their students.
- Developing kiosks to display information.

Information Dissemination

MDOT, working with other agencies, can develop and market the information that can be provided externally as a result of implementation of various ITS components. One of the principal methods of information delivery that has been repeatedly suggested is the use of on-line technology. This technology can include a home page, with instructions on how to access the information. It can be free of charge or it can include methods of subscription which require payment in return for a password for access to the information. Another method of delivery of transportation information is to a distribution source such as TCI. Both of these methods make use of existing communication network technology for distribution of transportation information. These alternatives and others should be explored in greater detail.

Tests of information dissemination might be pursued with employer human resource departments, who have an interest in safe and timely travel by employees. CCTV cameras on the freeway would be transmitted to employment centers and would allow people see the traffic conditions on the highways prior to beginning their trips. They could then make decisions about travel path or time of travel based on that information. Information might be transmitted to a commuter at home via telephone, fax, television, Internet, or to individual desk PCs for display at work. Another possibility is distribution of information via personal pagers. The pager distributor will, for a fee, provide subscribers with traffic alerts on specific routes that the customer has requested as part of their paging plan.

The kiosk is another technology for distribution of information that is now being explored in several metropolitan areas. MDOT may want to know more about its potential for the distribution of information to employment locations in the future.

Coordination with local trucking agencies, as well as local cab and shuttle services may also be initiated. These entities might be sources of information and also consumers of current traffic information to aid in their deliveries and reliance on the roadway network for safe and timely distribution of its products.

CONTRACTING ALTERNATIVES

Discussions regarding contracting alternatives are most easily looked at as discussions regarding the different ways in which various degrees of risk and responsibility can be traded amongst the parties participating in a project such that the choosing of the proper contracting alternative develops the desired results rather than the possibility of unintended and/or undesirable consequences. For example, the difference between a project's success or failure may depend on who or what organization has the authority and/or ultimate responsibility for determining system goals, objectives, developing system designs, creating system specifications, letting system contracts, making system changes, authorizing/financing system changes, and/or making the system work as intended. In addition, it is also important to recognize that whoever has the above responsibilities should have the proper technical competence to efficiently and effectively exercise their contractual authority.

The following sections provide insight into the above issues and a recommended course of action regarding which type of contract best is suited for ITS implementation in the Grand Rapids metropolitan area. However, even though this focus is on a recommended type of contract (Consultant/Contractor, System Manager, or Design/Build), it is important to note that the choosing of any particular contracting type does not necessarily require the choosing of any particular contracting method (Time and Materials, Firm-Fixed-Price, Cost Plus Fixed-Fee, etc.). The latter decision can often be made on a contract by contract basis during bid requesting and/or negotiations between the agency and the consultant, contractor, system manager, and/or design/build team.

Existing Agency Methodologies

Transportation Agency Practices

Transportation agencies have much experience and established procedures for procuring equipment and services for highway and bridge construction projects, as well as for obtaining design assistance for these types of projects. The following sections describe the established relationships between a transportation agency and contractors, and a transportation agency and consultants.

Constrtrction Contracts

To assure open and competitive bidding on government contracts, a process has evolved whereby transportation agencies have traditionally awarded contracts to the lowest bidder. To assure quality, many transportation agencies, including MDOT, have developed well defined processes such as their *Standard Specifications for Construction* manual, and have also developed detailed criteria whereby contractors must first be prequalified in order to even bid on certain projects. Then, contracts are awarded to the lowest prequalified bidder. This may work in theory on non-complex projects to prevent unqualified contractors from being awarded a job as the low bidder. However, marginal contractors or sometimes even non-qualified contractors can often be prequalified because the DOT's are afraid of potential litigation if they reject a given contractor's prequalification request. Under this scenario, when it comes time to award a contract, a truly unqualified but prequalified bidder can end up winning a contract if they are the lowest bidder. This can be especially problematic in ITS-related procurements since transportation agencies do not usually have enough in-house expertise to actually determine those contractors who are qualified or not. Furthermore, because transportation agencies are typically very liberal in approving contractual change orders, which effectively transform Firm-Fixed-Price contracts into Cost Plus Fixed-Fee contracts, the potential for cost overruns can be very high since unqualified bidders tend to underestimate the complexity and cost of projects in order to win jobs and later make-up their fee through various types of contractual changes.

Professional Services (Consulting) Contracts

In professional services (consulting) contracts, firms are not prequalified and projects are not necessarily awarded to the lowest bidder. Instead, contracts are awarded on the basis of who is the most technically competent to do a job, irrespective of price. This process, as stated under Title 23 of the United States Code of Laws and required of all contracts in which Federal funds are used, is essentially as follows:

1. An agency identifies the scope of work
2. A selection schedule is established
3. A list of professional firms is compiled
4. Qualification documents are requested
5. Qualification documents are evaluated
6. A shortlist of firms to be interviewed is composed
7. Interviews are conducted
8. Firms are ranked for selection
9. A contract is negotiated with the top-ranked firm. If an agreement cannot be reached, those negotiations are ended and negotiations are begun with the second-ranked firm, and so on down the line, until agreement is reached and a firm is selected
10. All firms involved receive post-selection communications

However, for agencies like MDOT where there is no "across the board" prequalification process for ITS-related professional services, ranking procedures may need to be created. It should be mentioned, though, that MDOT has in the past used project-specific prequalification processes for certain ITS-related professional services requests. One possibility for creating ranking procedures is to utilize some form of this prior project-specific prequalification procedure. Another possibility for increasing technical evaluation possibilities would be to hire an independent consultant to review the proposals, but that consultant would then not be able to bid on the projects in which they had developed the ranking procedures. This would potentially deprive the DOT of valuable sources of knowledge from consultants who might have otherwise been able to make significant contributions to a project's actual implementation. Furthermore, a lack of ITS-experienced personnel in a DOT's Contracts Office may put the agency at a significant disadvantage when it comes time to negotiate the multiple contracts for ITS design and implementation that may be required by this above selection process.

NASA/Department of Defense Models

In contrast to the above traditional transportation methodologies of explicit contractual separation behveen the design and implementation stages of a project, both the National Aeronautics and Space Administration (NASA) and the United States Department of Defense (DOD) typically utilize contractual unity between a project's design and implementation stages, especially on large-scale/complex programs that may consist of multiple sub-systems requiring integrated command, control, and intelligence; programs with challenges similar to those found with ITS.

For example, when the DOD needs a new airplane it does not contract with McDonnell Douglas for the design, and then have it built by a team headed-up by the Lockheed Corp. A major reason for this is that not all of a designer's knowledge can ever be transferred from their brains into contracting documents, therefore something inevitably ends-up being left out. Furthermore, when looking at formal contracting arrangements on complex projects like airplanes or ITS, it is important to understand that risk is directly related to cost. In other words, the more a bidder knows about a project or the agency developing a project, the smaller the amount of risk dollars that need to be added to a bid by a contractor. Conversely, the less one knows about a project, the greater the amount of risk dollars that need to be added to a bid, thus increasing the cost of a project. This is especially evident in either a NASA or a DOD project environment because major change orders are rarely approved. Unlike their DOT counterparts, NASA and DOD Firm-Fixed-Price contracts are just that, Firm-Fixed-Price. In light of this discussion of risk dollars, it is interesting to note that traditional transportation contracting methods can actually encourage distance relationships between designer and implementor, thus driving up costs. This is further encouraged whenever agency-bidder contact and question/answer times are excessively limited upon release of a Request For Proposals.

Similar to what will be described later in the Design/Build section of this technical memorandum, the path leading to the successful implementation of ITS projects is very similar to the path that has been used by both NASA and the DOD to put humans on the Moon. This may not yet be that evident to DOTs who are accustomed to dealing with bridge or highway projects in which concrete, steel reinforcing bars, and traffic signal heads behave a certain way and can be obtained by multiple vendors since there are established standards. However, many ITS devices do not have established standards and there are a multitude of components that must all work together in order for a project to be successful. Thus, the lesson to be learned is that it is no longer adequate to solicit items on a piece-by-piece basis for complex ITS implementations that require a systems integrator. The potential is too high for many dollars to be unnecessarily spent if there is too much distance between the agency, the design organization, and the implementation organization.

Formal Contracting Arrangements

As shown in Figure 7-7, there are three primary approaches for contracting ITS-related system design and implementation projects: Consultant/Contractor, System Manager, and Design/Build. The following sections describe each of these types and some of the major advantages and disadvantages of using them to implement ITS. Included are discussions regarding issues such as implementation schedule, constraints of current procurement laws, availability of qualified contractors, availability of MDOT staff, and number of contracts required.

Consultant / Contractor

The Consultant/Contractor procurement method is the one typically used for highway projects. It is based on the concept that almost all potential construction options are defined in Federal, state, and local *Standard Specifications for Construction* manuals. It is also based on the concept that critical system parameters can be fully specified and documented in a single set of contract documents such as a Plans, Specifications, and Estimate (PS & E) package, that a single contractor is best suited to implement the project, and that the only criterion of significance for selecting the contractor is the initial bid price. For ITS projects, this approach uses a consultant to perform the feasibility study and system design.

For example, MDOT would issue one contract with a consulting firm to design the system, and then MDOT would issue multiple contracts with different contractors who would implement each of the subsystems that were designed by the original consultant. The implementation contractor is completely responsible for system installation, checkout, documentation, and training. However, the DOT is responsible for installation monitoring activities and making sure that the system components -work together and actually perform the functions that they were originally intended to perform.

Advantages

The only advantage to the Consultant/Contractor approach in ITS-related projects is that an agency's basic procurement principles are maintained. Thus, MDOT's contracting office would not have to learn a new system for ITS-related project implementations.

Disadvantages

Any and all design gaps, buildability issues, and system integration during project implementation must be addressed by the DOT or another consultant without assistance from the original consultant since the first consultant's contractual obligations are over at this point. Furtherrnore, the extensive experience with this process for highway construction has resulted in a very rigid set of procedures and rules within most highway agencies that severely restrict the flexibility of system designers and implementors, and prove to be ". ..unduly cumbersome and counterproductive when applied to traffic control systems projects involving advanced technologies" [USDOT, FHWA, *Traffic Control Systems, Operations and Maintenance -- Expert Panel Report,* March 10, 1992; p. 211. It must be remembered that there are no standard specification books for ITS components, and no standard "recipes" that ensure all components will work together as intended. The following provides additional detail regarding some of the various reasons that the Consultant/Contractor approach is frequently ineffective for projects like ITS that involve electronics, computers, and communications equipment. For example:

- **Electronics technology is changing too rapidly.** A new generation of electronics equipment (computers, communications, software, etc.) is available every eighteen months. With a minimal three-year cycle from start of design to completion of construction, two generations of equipment will have evolved. The equipment can be obsolete before it is put into use.

- **Initial low bid is not the most important discriminator of system success and total system cost.** Operations costs, maintenance costs, training costs, equipment upgrade and compatibility, and related life-cycle costs are nearly always larger than initial procurement price. Furthermore, software development and system integration, key elements to the success of a complex system, are low bid items.

- **The complex nature of these projects is often beyond the experience and capability of traditional highway contractors.** However, since a majority of the cost under the Consultant/Contractor approach is generally associated with field construction activities, the prime contractor is often a roadway or electrical contractor that has little or no system integration or software experience.

- **DOTs usually have limited ability to understand and fully specify a complex system involving computers, software, and human interactions.** Furthermore, many of the human-factor issues that relate to system usability are typically addressed during implementation stages because of the need to meet special and unforeseen site-specific DOT user-requirements. For example, the end users of the system must define the operational requirements, but they usually do not have the experience needed to convert their needs into precise and unambiguous system specifications. Conversely, the analysts and software engineers who have to create the system may have limited DOT experience and therefore do not always understand the user's requirements.

Thus, the assumption that enough can be known about a project in order to be able to fully define its characteristics is invalid for ITS projects. Furthermore, with two or more organizations involved in the process, responsibilities of the design and implementation parties can become unclear. For example, due to the numerous parts that would have to be procured by a DOT under separate low-bid contracts, situations such as the possibility of functionally-specified computer cards purchased under one contract not being able to fit into controller cabinets purchased under a separate contract may become commonplace. No matter how well the Consultant/Contractor approach is for traditional highway projects, unless the procuring agency has a detailed and complete understanding of what they are buying, it does not work well for projects involving advanced electronics, computer, and software technologies.

System Manager

The System Manager procurement method divides the project into several sub-projects for each of the various sub-systems with the work overseen by a systems manager, often a consultant, who administers each contract in conjunction with MDOT, and who is responsible for integrating the several hardware and software sub-systems into an overall operating system. The System Manager converts the project plan into preliminary designs and defines sub-systems, develops PS&E packages for sub-systems, helps MDOT oversee the bidding and award of construction contracts, checks the work of implementation contractors, supervises construction, selects and procures computer and communications hardware components, manages the installation of equipment, develops and furnishes the system software, integrates and tests the sub-systems, provides necessary software documentation, and supervises the provision of operator training.

Advantages

As with the Consultant/Contractor approach, the System Manager approach maintains the basic procurement principles that an agency is accustomed to working with. However, the System Manager approach has the additional advantage of focusing on a single organization and defined source of accountability that is responsible for both design and subsequent software/hardware integration, thus avoiding controversies over responsibility for design problems that may arise. The involvement of agency personnel as part of the design team also results in improved coordination and tighter cost controls. Furthermore, because the agreement between the agency and the system manager is a negotiated professional services contract, which can more easily be adapted as project needs are refined, increased flexibility is provided to meet the specific project requirements. This approach also provides for the selection of contractors with specific sets of skills for each of the sub-systems. For example, one contractor can be hired to do the earthwork and install the conduit, while another contractor can be hired to integrate and test the electronics within the communications subsystem.

Disadvantages

A potential disadvantage to the System Manager approach is that detailed specifications must be developed to define each subsystem in order that an agency can receive bids and let contracts for each of the major subsystems. Unlike the Consultant/Contractor approach, since all work is coordinated by a System Manager, many potential and costly change can be avoided. Thus, any potential disadvantages of the System Manager approach may be outweighed by its potential to provide for a more cost effective method of procurement.

Design/Build

In the Design/Build approach, the DOT issues a single contract with a Design/Build team who is selected to handle all of the work associated with implementing the system. Any and all other necessary contracts with subcontractors are administered and paid for by this single entity, which maintains the ultimate responsibility for subcontractor performance and any cost overruns. For example, the Design/Builder is responsible for all aspects of the system, including detail system design, procurement of all equipment, construction of all system elements, integration of the various sub-systems, and final system checking, tweaking, and operational transfer of a fully functional system to the client. Except for the Design/Build feature of transferring all responsibility from a DOT to the Design/Build team, it is in practice very similar to the System Manager approach. However, unlike the System Manager approach where a DOT is ultimately responsible for all contracts, the consultant negotiates, lets, and is responsible for all contracts for equipment procurement and installation.

Advantages

Since the Design/Build approach combines both the design and construction of an ITS-related project into a single contract, it can result in a better understanding of the designer’s intent by the builder, minimize the schedule overruns that result from potential conflicts and communication gaps between designers and implementors, potentially decrease the number of after-bid changes, and reduce completion times by streamlining the equipment procurement process by allowing critical components to be ordered and sub-contracts let as soon as engineering details are completed. Design/Build also eliminates time consumed in bid preparation and contract award analysis for separate architectural, engineering, and/or contractor entities while at the same time retaining competition through one unified Design/Build price proposal.

Disadvantages

A disadvantage to the Design/Build approach is that it places a significant burden on the procuring agency to oversee the design and implementation activities and to ensure conformance to the design concept. These are activities that many traditional transportation agencies may not have the in-house expertise to accomplish. This is best expressed by the following: At their best, design-build procurements can serve to streamline the development process and free the private sector to exercise ingenuity and creativity in packaging and delivering construction solutions. But, at their worst, they can distance the owner and user from design influence and decision-making, decrease the participation of professional designers, and shift the onus for quality control and public accountability primarily to the customer. It is up to the procuring agency to determine the extent that they wish to be involved in any type of ongoing Design/Build review process. However, it should be mentioned that it can be especially detrimental to results if an agency chooses the “hands-off’ approach since the agency personnel with direct operational experience and needs would then not be involved with the detail design, and thus could not provide input and feedback during design and implementation. It is therefore critical for an agency to know exactly what they want, and to establish a framework which effectively ensures its delivery. To support this, it is possible to hire a second, independent, consultant to help develop the necessary scope of work and to help oversee the design & implementation activities of the primary Design/Build consultant.

Recommendations

The System Manager approach to ITS-related procurement and project implementation is recommended because it provides the most flexibility, enables the greatest degree of control over technical features and system cost, and allows for the ability to obtain an optimum mix of contracting resources for each segment of the project. In addition, the System Manager concept has been successfully used on several major traffic management and incident management systems around the country because it is an approach that recognizes the complexity of these systems, especially when viewed from the context of traditional highway construction projects. Furthermore, other major industry segments in both the public- and private-sector use it to successfully implement projects with similar elements of multi-discipline and advanced technology challenges.

In order for this recommendation to work, it is strongly recommended that MDOT seek a consultant experienced in ITS systems and software integration, rather than just a general system engineering type of consulting firm. For example, many people call themselves systems engineers, however, they usually deal with just one given system, such as communications. Not many people or organizations are true systems integrators; those who can combine multiple systems such as surveillance, communications, command, control, intelligence, etc. and ensure that all of the pieces work together in a synergistic manner.

Finally, it must be emphasized that the System Manager approach allows a DOT to benefit in multiple ways by capturing the System Manager’s expertise both as a designer, and as an entity experienced in ITS-related contract negotiations. For the duration of any contract with a System Manager, the procuring agency will always have the System Manager’s assistance for such activities as evaluation of ITS products bid by the contractors, submittal reviews, and contractor change-order analysis. Furthermore, under this scenario, the System Manager is always available to accompany the DOT to construction meetings in which it is felt that their attendance would be beneficial to the procuring agency.

CONCLUSIONS

This document has outlined a plan for the strategic deployment of an ITS system in the Grand Rapids metropolitan area. In the short term, this plan calls for the implementation of a freeway management system on priority corridors to facilitate incident management and address incident related congestion. In the future, the freeway management system will expand to encompass additional facilities and to coordinate with ITS activities undertaken by transit, local public works, and enforcement agencies.

While this plan identities priorities for implementation and makes recommendations for activities in the initial, short, medium, and long term, it is important to note the limitations associated with these recommendations. Any plan, such as this one, that incorporates "advanced technologies" as a component must change to reflect and utilize new technologies and applications. The plan must also change to reflect changing circumstances in the metropolitan area. Thus, the recommendations set forth in this document should be considered guidelines, rather than constraints. And these recommendations should be re-evaluated in light of future needs, future technologies, and future circumstances.

Regardless of the specific technologies used, or the user services implemented, the overriding focus of the ITS system must be to safely and efficiently meet the transportation needs of the Grand Rapids metropolitan area and other roadway users.