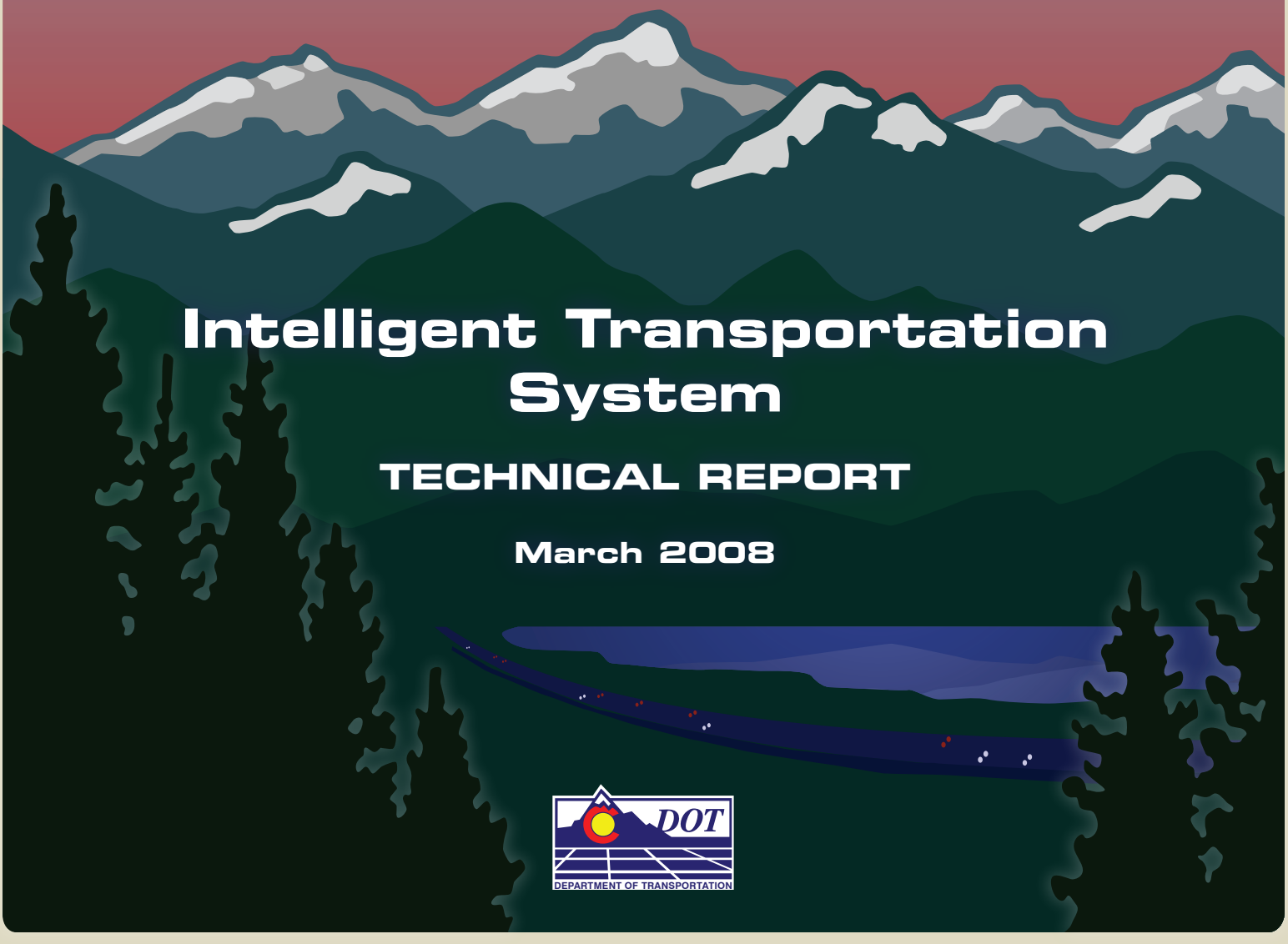
MOVING COLORADO

VISION FOR THE FUTURE

2035 Statewide Transportation Plan



Intelligent Transportation System

TECHNICAL REPORT

March 2008

DEPARTMENT OF TRANSPORTATION

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GLOSSARY OF ACRONYMS

C2C	Center-to-Center
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CSP	Colorado State Patrol
CS TMC	Colorado Springs Transportation Management Center
CTMC	Colorado Transportation Management Center
CTMS	Colorado Traffic Management System
DRCOG	Denver Regional Council of Governments
DTD	Division of Transportation Development
EJT TMC	Eisenhower Johnson Tunnel Transportation Management Center
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
HLT TMC	Hanging Lake Tunnel Transportation Management Center
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IT	Information Technology
ITS	Intelligent Transportation Systems
MACC	Multi-Agency Coordination Center
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
PDA	Personal Digital Assistant
POE	Port-of-Entry
SEA	Systems Engineering Analysis
TMC	Transportation Management Center
T-REX	Transportation Expansion Project
VMS	Variable Message Sign

INTELLIGENT TRANSPORTATION SYSTEM (ITS)

Background

Traffic congestion is one of the most significant issues faced by communities across Colorado, the United States, and the World. Congestion impacts all modes of transportation and all travelers. Congestion results in extra travel time to the destination, wasted fuel and increased emissions. In addition, congestion itself can contribute to increased crashes causing further delays. Increased road rage and decrease in quality of life are among some of the other negative effects of congestion.

Congestion on the roadway network is further compounded by incidents such as adverse weather conditions, accidents and stalled vehicles. These incidents can result in loss of life and damage to property. In addition, these situations further reduce the capacity of the state highway system, increase existing congestion and can cause secondary accidents. Furthermore, these incidents can lead to increased congestion on adjoining roadways that serve as alternate routes.

Fact:
Traffic congestion in the United States for 2003 resulted in 3.7 billion hours of travel delay, 2.3 billion gallons of wasted fuel costing the nation $63.1 billion dollars.

Source – 2005 Urban Mobility Report developed by Texas Transportation Institute

The following are some examples of how congestion impacts travelers in Colorado on a daily basis:

- **Personal Travelers** (such as commuters, vacationers, etc): The extra time spent in traffic congestion may cause lost productivity at the work place or lost time for social and recreational purposes.

Fact:
Gridlock on the mountain segment of I-70 is responsible for nearly $ 1 billion annually in negative financial impacts to Colorado.

Source - Denver Metro Chamber of Commerce and Metro Denver Economic Development Corp.

- **Public and Business Service Providers** (such as Police, Ambulance, plumber, plumbing company etc): Emergency service providers encounter delay in responding to medical, criminal and disaster situations. Business services respond to fewer calls per day and cost of business will increase due to extra time spent in congestion.

- **Commercial Truckers**: Delivering on time is critical in the trucking industry. Delayed shipments can result in loss of productivity and ultimately in increased costs to consumers.

Need for ITS in Colorado

Between 1990 and 2006, Colorado's population grew by about 46 percent from 3.2 million to 4.7 million. By 2035, Colorado's population is expected to increase to 7.8 million.[1] According to

[1] Colorado Department of Local Affairs Demography Section, North Front Range Metropolitan Planning Organization & Pikes Peak Council of Governments.

CDOT Division of Transportation Development (DTD), since 1990 the number of state highway system center-lane miles increased by 1.3 percent to about 9,200 miles. During that same time period, however, the annual number of vehicle miles traveled increased from 17.8 billion to 26.1 billion, a 47 percent jump. As of 2003, more than 75 percent of the state highway system's 2,300 congested lane miles are in the urban areas. Given current funding constraints and budgetary limitations, it is neither possible nor practical to add enough lane miles or build new roadways to alleviate this congestion.

In order for the transportation system to remain functionally viable, it must be managed using a combination of transportation applications and technologies. One management strategy that the Colorado Department of Transportation (CDOT) has successfully employed to maximize, enhance and improve system productivity is the application of Intelligent Transportation Systems (ITS). ITS uses various technologies in an integrated fashion to improve the safety, efficiency, productivity, inter-modal connectivity and inter-jurisdictional coordination of the surface transportation system by managing traffic, incidents and providing traveler information.

Examples of ITS Applications

There are numerous examples of ITS applications. The following are a few examples of ITS applications that are being used within Colorado.

Ramp Meters – By regulating the number of vehicles entering the freeway, congestion on the freeway can be reduced. There are over 85 ramp meters in Colorado, which are primarily located in urban areas.

Traffic Cameras - Traffic conditions can be monitored using Closed Circuit Television (CCTV) cameras where coverage is available. There are over 300 traffic cameras on freeways and state highways in Colorado.

Weigh-In-Motion – This application allows commercial vehicles that are enrolled in the Pre-Pass Program to by-pass the Port-of-Entry (POE) provided they are within legal size and weight limitations and all vehicle credentials are in order. Colorado enjoys the highest by-pass rate in the nation at about 50%. This translates to significant cost savings for the commercial vehicle industry as well as the State.

Travel Time Application – Real-time travel times are posted on Variable Message Signs (VMS) on the roadway and the traveler information website (www.cotrip.org) using data that is collected by ITS devices. This application has been implemented on the I-70 corridor (in both directions) from Golden to Vail. Statewide, there are about 300 VMS, which are used to post traffic, incident, regulatory and other relevant messages.

Traveler Information – Travelers using the website (www.cotrip.org) and 511 (traveler information) statewide automated phone system are provided with real-time information regarding traffic conditions, incidents, road and weather conditions, major construction, road closures, etc.

Fact:
Potential benefits attributed to ITS show: speeds increased by 16 percent, travel times on congested corridors were reduced by 22 percent, primary accidents decreased by 15 percent, secondary accidents decreased by 30 percent and average incident duration decreased by 50 percent, depending on the specific circumstances.

Source-FHWA

Transportation Management Centers (TMCs) These centers monitor the transportation network for heavy traffic, incidents, road and weather conditions, etc., using traffic surveillance cameras, traffic and weather data collection sensors and the advanced traffic management system. In addition, when connected to other centers such as police, fire, major municipalities and emergency response centers, the traffic management centers provide a valuable support role during major incidents, weather events, wild fires, etc. There are four major TMCs in Colorado: Colorado Transportation Management Center, Hanging Lake Tunnel TMC, Eisenhower Johnson Tunnel TMC and Colorado Springs TMC.

Accomplishments Since the 2030 Statewide Transportation Plan

Since the 2030 Statewide Transportation Plan, CDOT has continued to deploy ITS infrastructure statewide consisting of a fiber optic communications backbone, ITS devices and computer and network equipment necessary to operate the system. Some of the accomplishments include:

- **Colorado Transportation Management Center (CTMC) Relocation** – In late 2006, the CTMC was relocated to Golden from its interim facility in Lakewood. The facility was expanded to include additional operator consoles, state-of-the art network and computer center, and a media broadcasting room. The CTMC now has a state-of-art video wall that enables the operators to monitor the ITS infrastructure and quickly display camera images and other operational materials and maps to meet specific operational situations. All of the ITS Branch staff work at the CTMC. The facility remains a 24/7 operation. It is physically connected via fiber optics to the Eisenhower Johnson Tunnel TMC and Colorado Springs TMC.

  Fact:
  CDOT has estimated that if the total amount of closures (related to truck traffic) incidents could be reduced by as little as 10 percent on I-70, closure time would decrease by as much as twelve hours per year, which results in a savings of approximately $ 9.6 million dollars.

- **Communication Infrastructure and C2C Connectivity** - Fiber optic communications were deployed on I-70 from Denver west to Frisco. This provided connectivity to ITS field devices, lateral connections to local law enforcement in the corridor and center-to-center (C2C) connectivity between CTMC and the Eisenhower Johnson Tunnel TMC. Fiber optic communications were also deployed on I-25 from Denver south to Pueblo. This provided connectivity to ITS field devices and C2C connectivity between CTMC and the Colorado Springs TMC. C2C connectivity also exists between CTMC and several local centers including the Office of Emergency Management's Multi-Agency Coordination Center (MACC), which offers the ability for state, federal, and local agencies to come together in a central location to coordinate the response to emergencies and disasters throughout the state.

- **Travel Time Application** - Real-time travel times have been rolled out on the I-70 corridor from Golden to Vail. This has been received very favorably by the traveling public and with requests to expand the application to other corridors. CDOT plans on expanding the real-time travel time application on strategic freeway corridors in the Denver metropolitan area. In conjunction with this real-time travel time application, CDOT will be able to maximize on and use the existing infrastructure to enhance other services such as: improved incident and traffic management strategies. Related to this at the travel time system level, CDOT is developing an "alarm" feature that will notify operators regarding potential problems on the corridor so that they can evaluate the situation (using CCTV and other devices) and initiate appropriate measures more rapidly.

  Fact – There are more than 400,000 vehicles in the Front Range that have toll tag transponders.

- **511 Statewide Implementation** - For more than 15 years CDOT has provided statewide traveler information via an automated phone system, which required callers to dial a ten-digit phone number from their specific calling area. However, in November 2006 CDOT ITS completed a statewide 511 implementation, which consolidates multiple calling area numbers into the abbreviated one-point of contact number of 511. CDOT ITS worked with landline and wireless carriers to activate 511 statewide throughout their coverage areas. In addition, CDOT ITS implemented a call transfer feature to allow callers to access neighboring states' traveler information systems. In the near future, CDOT ITS intends to incorporate real-time travel times into the 511 statewide traveler information system. Longer term, access to other transportation related provider's (RTD, other transit and municipal agencies, tourism, etc.) information will be available through 511 and voice recognition features will be incorporated into the 511 statewide traveler information system.

  Fact:
  In 2006, CDOT 511 Statewide traveler information phone system received over 1 million calls.

- **Traveler Information Website** – For more than 7 years CDOT has provided statewide traveler information via the cotrip website at www.cotrip.org. The website contains the latest information on road and weather conditions. In addition, it has real-time information as it relates to traffic cameras, electronic signs and weather stations. The website is getting increasingly popular each year.

  Fact:
  In 2006, www.cotrip.org CDOT traveler information website registered nearly 500 million website hits and transferred approximately 4 terra bytes of information.

- **Development of ITS Strategic Plans and Architectures** - Since completion of the 2030 Statewide Transportation Plan, CDOT ITS has worked with CDOT Regions 1, 2, 3, 4 and 5 to develop Regional ITS Strategic Plans and Architectures. The Plans were developed using a collaborative effort involving numerous stakeholders. The Plans are a "road map" for implementing a system of strategies over a period of time. They identify transportation needs that can be addressed by ITS applications within the context of a systematic approach and relevant institutional and operational elements required for effective, integral and regional transportation systems. The Architectures are required by the Federal Highway Administration (FHWA) as a condition of receiving and using federal funds on ITS applications. FHWA requires that a Regional Architecture address specific elements within the Architecture that foster integration between existing systems and ensure that subsequent systems will be integrated into existing systems. The Architecture establishes a framework to facilitate regional deployment of ITS projects, while ITS standards help to ensure compatibility and maintainability of the deployed technologies. The Plans/Architectures can be accessed at www.cotrip.org/its/arch.html.

- **Statewide ITS Inventory and Maintenance Management System in SAP** – Prior to SAP implementation (an enterprise software system), CDOT ITS Branch working with stakeholders developed the ITS Maintenance Management System (ITS MMS) framework and detailed system functional requirements. CDOT selected SAP as its ERP system to replace, consolidate and integrate numerous legacy and stand-alone financial and business systems. When CDOT implemented the SAP system, the ITS maintenance management system functional requirements were migrated into SAP. Beginning in November 2006, CDOT began populating the ITS inventory portion of SAP. The inventory of ITS infrastructure is nearly complete. As part of the inventory, ITS device as-builts are also being developed. This complete ITS inventory will be available in SAP for ITS, Region's and DTD maintenance staff to perform maintenance activities using a work order based system. This will allow CDOT to track expenditures for labor, materials, equipment, warranties, device-life cycles, etc., as well as preventative maintenance protocols and cycles, and device and system condition.

- **Statewide ITS Capital Replacement Program** – Over the years, the funding for maintenance and operations remained the same even as the ITS infrastructure increased substantially. CDOT ITS Branch working with stakeholders was successful in continually demonstrating a clear need for additional maintenance resources. Through such efforts, the Transportation Commission approved the continuance of the ITS Capital Replacement Program at about $4.0 million per year, which is currently programmed through FY09.

- **Standards, Specification and Guidelines** – CDOT ITS has worked with numerous stakeholders to develop ITS device specific standards and specifications. Also, CDOT ITS developed Statewide ITS Implementation Guidelines to assist the Regions with deployments.

- **TMC Operations Manuals** - CDOT ITS has been working with the four major TMCs to develop Operations Manuals. The purpose of the Manuals is to document TMC procedures, protocols and practices, define step-by-step processes that the TMC employs in carrying out its daily functions, identify roles and responsibilities regarding TMC interoperability and remote operations of a TMC by another TMC and recommend training and cross-training activities. The Manuals will be completed by summer 2008.

- **DRCOG ITS Pool Projects** – In 2005 the DRCOG Board established a Regional ITS Pool for the purpose of implementing ITS projects identified in the DRCOG ITS Strategic Plan. CDOT ITS has been successful in acquiring funding to implement real-time travel time applications on: I-25 from the Denver Central Business District to 120th Avenue, US 36 from I-25 to Boulder, US 6 from I-25 to C-470, C-470 from I-25 to I-70, which are scheduled to be completed in the fall of 2008, and on I-70 from DIA to C-470, which is scheduled to be completed by winter of 2008. Also in the near future, the real-time travel time application is planned for I-25 from Lincoln Avenue to Pueblo.

- **T-REX** - The project deployed over $20 million (over 200 permanent ITS devices and an additional 250 devices were deployed during the project to manage traffic during construction) of ITS infrastructure to support traffic management and incident management functions on I-25 and I-225 in the Denver Metro region. Also, the project provided center-to-center connectivity between the CTMC and the following seven local (city and county) traffic operations centers: Aurora, Englewood, Greenwood Village, Littleton, Lonetree, Arapahoe County and Douglas County. Maintenance responsibilities for the ITS infrastructure will be turned over to CDOT ITS in January 2008.

- **Partnerships** – Through partnership agreements with both public and private entities, CDOT has deployed communication infrastructure along several key corridors. Public entities include Colorado Springs (Traffic & Municipal Water), Douglas County, Eastern School District, School of Mines, etc. CDOT is also considering working with private entities such as Xcel and other Utilities, etc.

ITS STATEWIDE STRATEGIC PLAN

ITS Strategic Plan

The ITS activities within CDOT are guided by the Statewide Strategic Plan in conjunction with the pertinent Regional Strategic Plan. The Statewide Strategic Plan was developed by a cross-functional ITS Steering Committee, with input from staff at headquarters and the CDOT regions. The Steering Committee helped to develop a department-wide vision and strategic direction for ITS. The Strategic Plan identified the following vision for ITS in the state of Colorado:

> *Provide reliable, accurate, and timely traveler information, and real-time traffic management and operation of the highway system through fully integrated, coordinated and maintained Intelligent Transportation Systems, so that users are able to make decisions that enhance and improve their choice of travel, mode, route and time, thereby resulting in a more productive, efficient and safe transportation system.*

The ITS Strategic Plan identifies how ITS core services and business-related objectives align with the CDOT investment categories, and identifies recommended strategies within each core service area. It outlines the highest level ITS strategies and identifies the resources and implementing actions required to achieve them. The Plan discusses the benefits of ITS and several performance-measure metrics associated with ITS. The Plan priorities have received broad-based support across CDOT regions and headquarters. The ITS Strategic Plan will be used to provide guidance and direction for current and future ITS investment and implementation. The ITS Strategic Plan is discussed in greater detail later in this chapter.

CDOT Investment Categories and ITS Core Services

CDOT has established four transportation investment categories and associated goals that provide policy direction for investments. The ITS Strategic Plan has identified ITS core service tools and services activities that directly support the investment categories of mobility, safety, system quality and program delivery. As an example, five core service areas and their related work activities are described below:

- **Traveler Information** – Refers to the collection and dissemination of data regarding road conditions and utility. The primary objective of traveler information is to improve the mobility of travelers. This is accomplished by collecting traffic and road condition data and disseminating it to transportation users both before and during their trips. Several activities are underway to collect and report enhanced traveler information to the public. Using toll tag readers, other detection devices and upgraded system software, ITS provides travel times on roadside electronic signs and provides it and speed map information on the CDOT website and intends to integrate travel times to the 511 statewide automated phone system.

- **Traffic Management** – Involves the management of highway traffic flow to ensure the highest utilization of the transportation infrastructure during both normal (congested/non-congested) and unusual (incidents and weather) conditions. The primary objective of managing the traffic flow is to improve mobility. For example, ramp meters are one way to control the number of vehicles entering the freeway over a set time. Also, certain corridors are being implemented with "trail blazer" signs, which will be used to divert travelers to alternate routes in case of extreme traffic events and/or incidents.

- **Incident Management** – Relates to the management of an incident and related highway traffic. Like traveler information and freeway management, mobility is the primary objective of incident management, although safety is an important aspect as well. The goal of incident management is to reduce the response times for incidents, clear roads of obstructions, keep traffic moving and minimize secondary incidents. ITS has worked in conjunction with the CDOT Regions, Colorado State Patrol, local law enforcement, emergency management personnel and other local stakeholders to develop Incident Management Plans (IMP). IMPs outline agency roles and responsibilities, identify incident operational procedures and alternative routes, staging areas, available equipment and contact personnel. Currently, there are 10 completed IMPs statewide on specific corridors. In addition, two other IMPs are scheduled to be completed shortly.

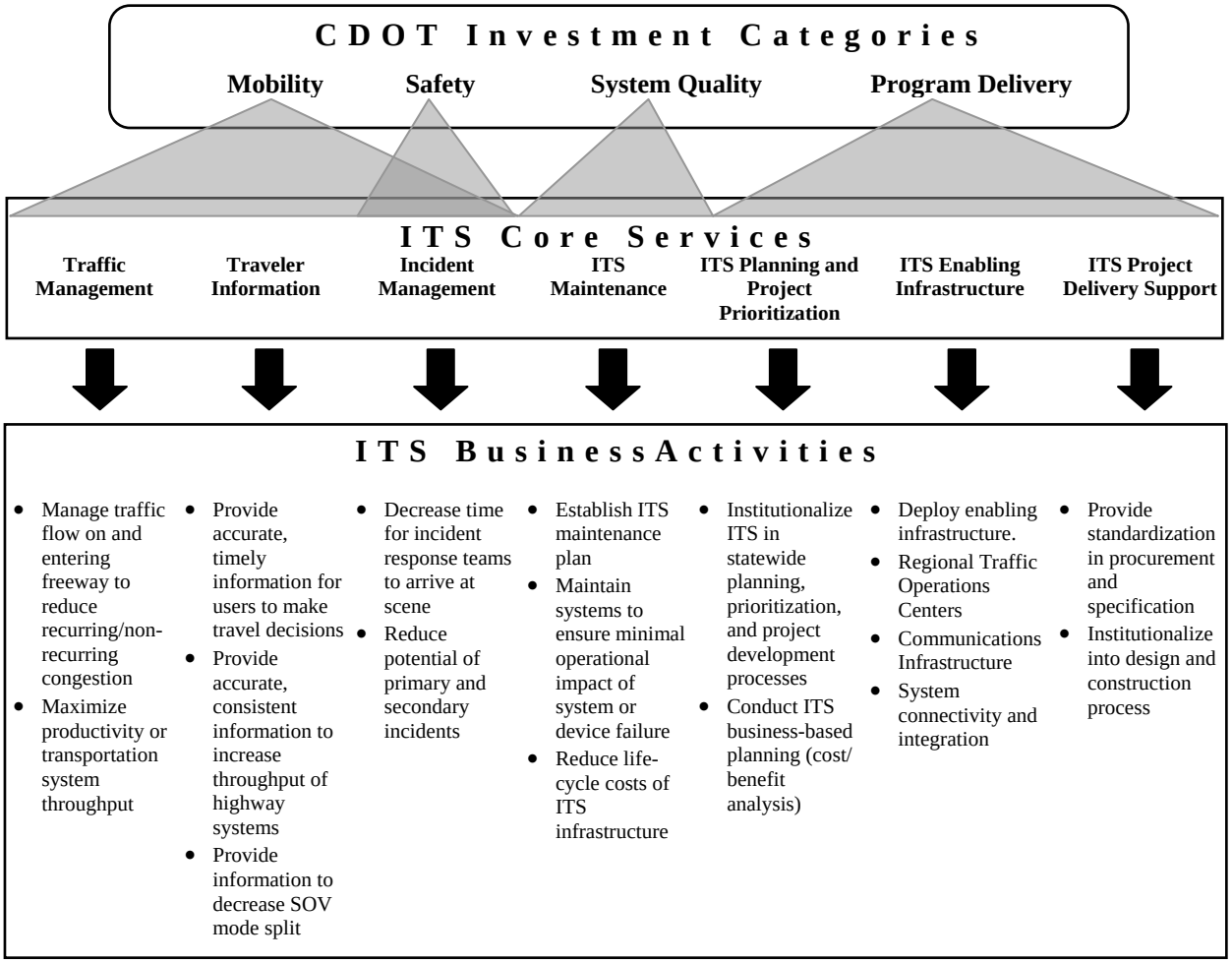
  Fact:
  Another extremely effective incident management strategy is the courtesy patrol. The courtesy patrol operates primarily in the Denver Metro area and responds to over 15,000 incidents a year. CDOT ITS dispatches the courtesy patrol and monitors courtesy patrol performance objectives.

- **ITS Maintenance Management** – This refers to a system that includes an inventory of devices, work order management capabilities and the ability to track performance and maintenance activities. It also requires establishing criteria for devices, equipment and systems regarding mean-time failure and life-cycle cost projections and institutionalizing a capital replacement program.

- **ITS Planning and Project Prioritization** – Refers to those support functions that enable the delivery of CDOT's ITS programs and services. The goal of this program area is to ensure that ITS planning is institutionalized into the statewide transportation planning process, and to perform comprehensive cost/benefit analytical planning for the deployment of ITS devices and systems. A related goal of ITS planning is to incorporate ITS into the project-level design process.

Figure 1 shows the objectives that are accomplished through the delivery of each ITS core service area. The core services identify the major ITS program areas and functions that support CDOT Investment Categories.

Figure 1. ITS Core Services/Business Objectives that Support CDOT Investment Categories



ITS Strategies

CDOT's role is to provide statewide leadership by deploying the enabling infrastructure, developing partnerships, establishing policies and procedures with stakeholders to ensure integration and seamless access to data, and by providing advocacy for those ITS investments that have a strong business case.

ITS is a significant element of CDOT's transportation tools in providing highly cost-effective strategies for meeting Colorado's current and future transportation needs by:

- Improving mobility through maximizing the productivity of the transportation system by using ITS to increase the throughput of passengers and vehicles on the transportation system. This effectively increases the capacity of the existing transportation system. CDOT uses ITS to continuously manage and fine tune the operation of the transportation system in response to travel demand and in the event of incidents which interrupt normal operations.

- Improving mobility through providing travel choices and increasing travel efficiency by providing access to comprehensive, reliable, accurate and timely traveler information. This allows travelers to make informed decisions concerning their travel prior to and during travel. ITS enables travelers and businesses to choose travel time, mode and route more efficiently based on real-time information regarding travel conditions. This helps spread the volume of travelers among modes and over travel periods, thereby reducing the costs of doing business and enhancing the quality of life in Colorado.

- Increasing safety for the traveling public by enabling faster response to incidents and reducing incidents through active traffic and incident management. A secondary mobility benefit is realized where Incident Management Plans have identified alternative routing that is used during incidents. CDOT uses a combination of ITS technologies to enhance the safety of the traveling public by monitoring system operations, planning and managing transportation affected by special events, and providing travel-related weather advisory information.

- Enhancing intermodal connectivity and inter-jurisdictional coordination by promoting and supporting seamless connectivity between multiple modes of transportation and Colorado's ITS systems. CDOT envisions information being managed as a resource that enhances intermodal connectivity between services provided by public and private transportation providers.

The Plan identifies 14 strategies and 33 implementing actions that address the issues identified by the ITS Steering Committee. The strategies fall into three major categories: policy and procedures, statewide strategic investment and technical assistance. The strategies and their relationship to CDOT ITS Core Services are shown and summarized in **Table 1**.

Table 1. CDOT ITS Strategies Related to ITS Core Services

Core Services	Strategies
Traffic Management	• Establish active traffic management in priority corridors.
Traveler Information	• Continue statewide deployment of ITS devices used for collecting pre-trip and en-route travel planning information. • Develop the Advanced Traveler Information System – disseminate statewide traveler information.
Incident Management	• Use real-time road condition information to deploy and assist with incident response. • Use active traffic management capabilities to reduce congestion arising from recurring/non-recurring incidents and provide traveler information about incidents.
ITS Maintenance	• Establish a statewide ITS maintenance planning, replacement and budgeting process.
ITS Planning and Project Prioritization	• Conduct statewide ITS deployment planning and provide leadership for implementing the statewide ITS enabling infrastructure. • Use performance measures to evaluate ITS contributions to CDOT investment categories. • Institutionalize ITS into the statewide and regional planning processes. • Institutionalize ITS into CDOT's project scoping processes.
ITS Enabling Infrastructure	• Deploy ITS enabling infrastructure on a statewide basis.
ITS Project Delivery Support	• Establish statewide ITS device procurement specifications and guidelines. • Establish policies, procedures, and provide guidelines for inspection and acceptance of ITS components. • Develop and establish statewide design standards for ITS systems and devices.

Implementation of ITS Strategies

The Strategic Plan includes details of each implementing action item such as a description, scope of work, prioritization, identification of responsibilities and expected durations. Many of these actions have been implemented through ongoing work. However, a considerable amount of work remains to be performed. There is broad agreement from the CDOT Regions that statewide leadership is required to implement this plan. The following areas guide the implementation of the ITS Strategic Plan.

- The ITS Branch will take the lead role, be responsible for and facilitate coordination, planning, development and implementation of statewide strategic investments of ITS systems and devices that pertain to the enabling infrastructure, policies and procedures, standards and specifications and performance measures.

- The ITS Branch will provide progress reports on action implementation status to the IT/ITS subcommittee and the EMT to ensure accountability and strategy implementation.

- The Regions will actively participate with implementation of statewide strategic investments, be responsible for implementation of regional strategies and action items, and initiate and facilitate ITS implementation through the Regional Transportation Planning process.

Statewide/Regional ITS Architectures and Regional ITS Strategic Plans

National ITS Architecture - The Transportation Equity Act for the 21st Century (TEA-21) requires all ITS projects funded from the Highway Users Trust Fund be in conformance with the National ITS Architecture and appropriate standards. The National ITS Architecture defines the ITS system components, key functions, organizations involved in developing an architecture and the type of information to be shared between organizations and between parts of the system. The implementing Federal Rule requires the National ITS Architecture be used to develop a local implementation, or a "regional ITS architecture." In addition, all ITS projects must be developed using systems engineering analysis (SEA) process. This approach to designing projects employs an iterative process in the design, testing and evaluation of implementation. CDOT is in the process of developing SEA guidelines to be used in conjunction with ITS Regional Architectures regarding project implementation.

Statewide ITS Architecture - The purpose of the Statewide ITS Architecture is to facilitate the comprehensive integration of ITS services deployed throughout the entire State of Colorado. While four regional ITS Architectures have already been developed within Colorado (see Regional ITS Architectures). There is still a need to establish an ITS framework (architecture) from a statewide perspective. The Statewide ITS Architecture is intended to compliment rather than supersede the existing regional ITS architectures by addressing the coordination and integration requirements of state-level services between multiple regions and jurisdictions. Thus, aspects of the Regional ITS Architectures have not been duplicated in the Statewide ITS Architecture and the deployment of intra-regional ITS applications will be implemented in accordance with the applicable Regional ITS Architecture.

The Statewide ITS Architecture is not required by the Federal Rule due to the existing Regional ITS Architectures, however, CDOT has decided to develop this architecture to serve as the framework for integrating the following statewide services throughout Colorado:

- Statewide Traveler Information,
- Commercial Vehicle Operations,
- Traffic Management including HOV and HOT facilities,
- Maintenance and Construction Management, and
- Emergency Management.

Regional ITS Architectures - Since completion of the 2030 STATEWIDE TRANSPORTATION PLAN, CDOT ITS has worked with CDOT Regions 1, 2, 3, 4 and 5 (Region 6 is currently being updated) to develop Regional ITS Architectures (see section titled Status of Regional ITS Plans and Regional ITS Architectures). The Architectures are required by the Federal Rule as a condition of receiving and using federal funds on ITS applications. FHWA requires that the "region" address specific elements within the Architecture that foster integration between existing systems and ensure that subsequent systems will be integrated into existing systems. The Architecture establishes a framework to facilitate regional deployment of ITS projects and ensure institutional agreement and technical integration for the implementation of ITS projects as identified in the ITS strategic plan. ITS standards help to ensure compatibility and maintainability of the deployed technologies.

The Federal Rule requires that a regional ITS architecture includes, at a minimum, the following eight elements:

1. A description of the region,
2. Identification of participating agencies and other stakeholders,
3. An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture,
4. Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture,
5. System functional requirements,
6. Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture),
7. Identification of ITS standards supporting regional and national interoperability, and

8. The sequence of projects required for implementation.

CDOT ITS incorporated the Southeastern and Western Architectures into Turbo Architecture, which is a software tool that will provide users: enhanced functionality in working with the required Architecture elements (identified above), the ability to access physical and logical diagrams at multiple levels, and will facilitate consistency, version control, maintenance and updating of the Regional Architecture. CDOT ITS is currently incorporating the Region 4, DRCOG and Statewide Architectures into Turbo.

Regional ITS Strategic Plans - Since completion of the 2030 STATEWIDE TRANSPORTATION PLAN, CDOT ITS has worked with CDOT Regions 1, 2, 3, 4 and 5 (Region 6 is currently being updated) to develop Regional ITS Strategic Plans. The Plans were developed using a collaborative effort involving numerous stakeholders. The Plans are a "road map" for implementing a system of strategies over a period of time. They identify transportation needs that can be addressed by ITS applications within the context of a systematic approach and relevant institutional and operational elements required for effective, integral and regional transportation systems.

Status of Regional ITS Plans and Regional ITS Architectures

The following Regional ITS Strategic Plans and Regional and Project Architectures have been completed. These include:

Fact:
Completed ITS Strategic Plans and Architectures are available on www.cotrip.org.

- June 2000 – I-25 Southeast Corridor Project Level (T-REX) ITS Architecture.
- May 2001 – Pueblo Freeway Management System Project ITS Architecture (I-25 and US 50), Colorado Springs Traffic Operations Center-to-Center (C2C) Project ITS Architecture, and CDOT Region 2 ITS Architecture.
- December 2001 – Denver Regional ITS Architecture. The T-REX Project Level Architecture was incorporated into the DRCOG Regional ITS Architecture.
- March 2003 – Denver Regional ITS Strategic Plan.
- February 2004 – Region 4 ITS Architecture.
- March 2004 – Region 4 ITS Strategic Plan.
- November 2006 – Regional ITS Strategic Plan for Southeastern Colorado and Regional ITS Architecture for Southeastern Colorado.
- November 2006 – Regional ITS Strategic Plan for Western Colorado and Regional ITS Architecture for Western Colorado.
- November 2007 – Denver Regional ITS Architecture.
- December 2007 – Denver Regional ITS Strategic Plan.

The following ITS Strategic Plans and Architectures are being updated:

- Region 4 ITS Architecture was incorporated into Turbo Architecture will be completed in April 2008.
- Statewide ITS Architecture to be completed in May 2008.

Further information regarding these documents can be obtained on the COTRIP website at **www.cotrip.org**.

STATE OF THE SYSTEM

The ITS system is composed of several key components that work together to improve the safety, efficiency and productivity of the surface transportation system. The key components include:

- Infrastructure
- Transportation Management Centers
- Software System(s)
- Owners
- Partners
- Users
- ITS Performance Measures

Infrastructure

Since 1990 the state has invested more than $150 million dollars in ITS infrastructure. This infrastructure consists of more than 1,200 field devices and over 500 miles of fiber optics communication infrastructure.

ITS field devices primarily consist of: variable message signs, traffic cameras, weather stations, high-occupancy vehicle (HOV) & High Occupancy Toll (HOT) lanes systems, weigh-in-motion (WIM) systems, traffic detectors, ramp meters, call boxes, tunnel lane control signs, etc. However, this does not include the thousands of traffic signals within the state.

ITS infrastructure also includes communication infrastructure consisting of wire line and wireless communications and communication networking equipment. **Figures 2 and 3** show the existing ITS fiber network infrastructure in the state. It is important to note that the ITS infrastructure investment identified does not include investment by local entities (cities, counties and transit agencies) within the state.

Fact:
Over 40 different types (functional categories) of ITS devices such as; traffic cameras, variable message signs, radar detectors, blank out signs, lane control signs, fog visibility system, etc are deployed within Colorado.

Figure 2. Statewide ITS Fiber Network Infrastructure

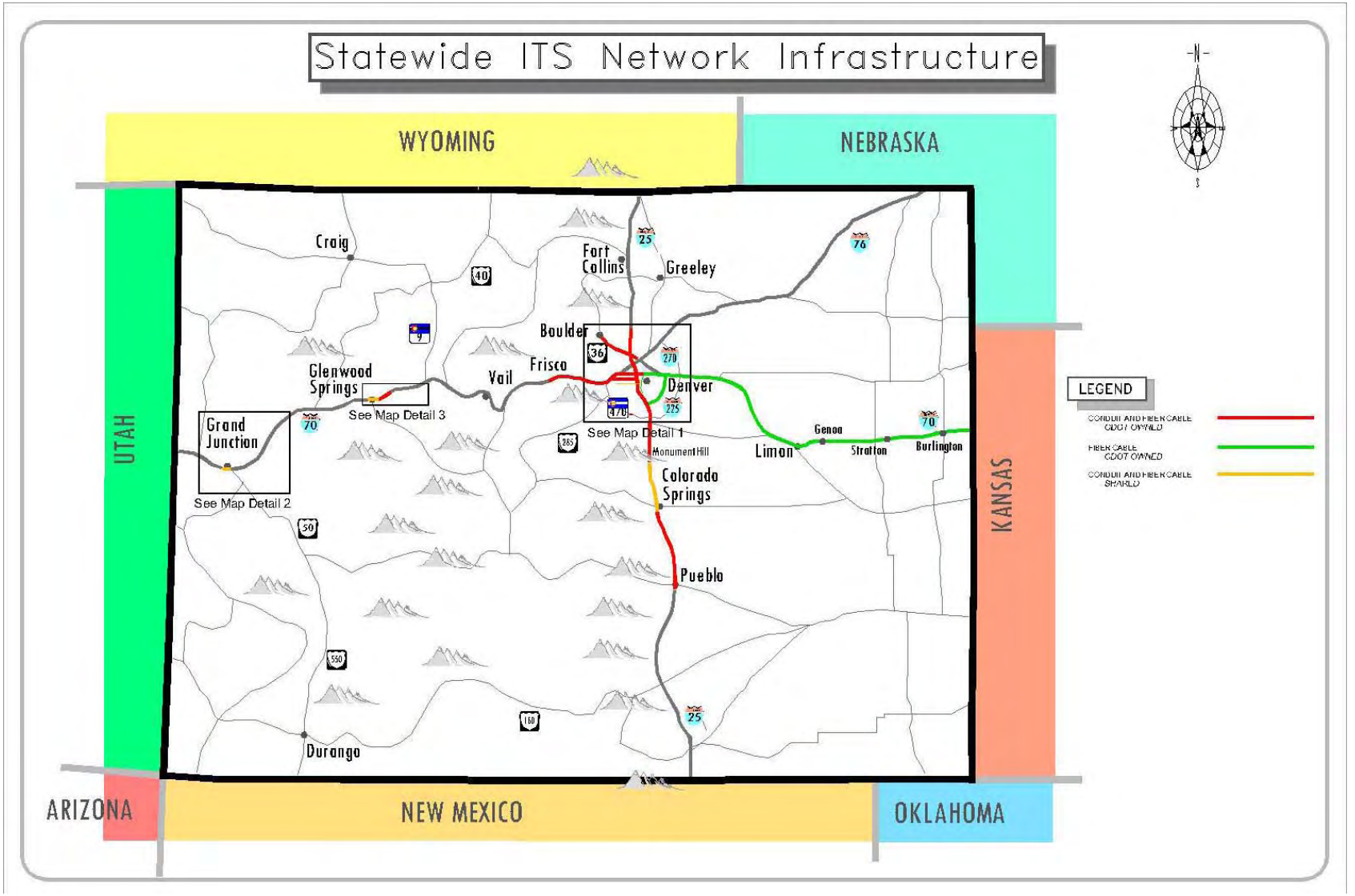
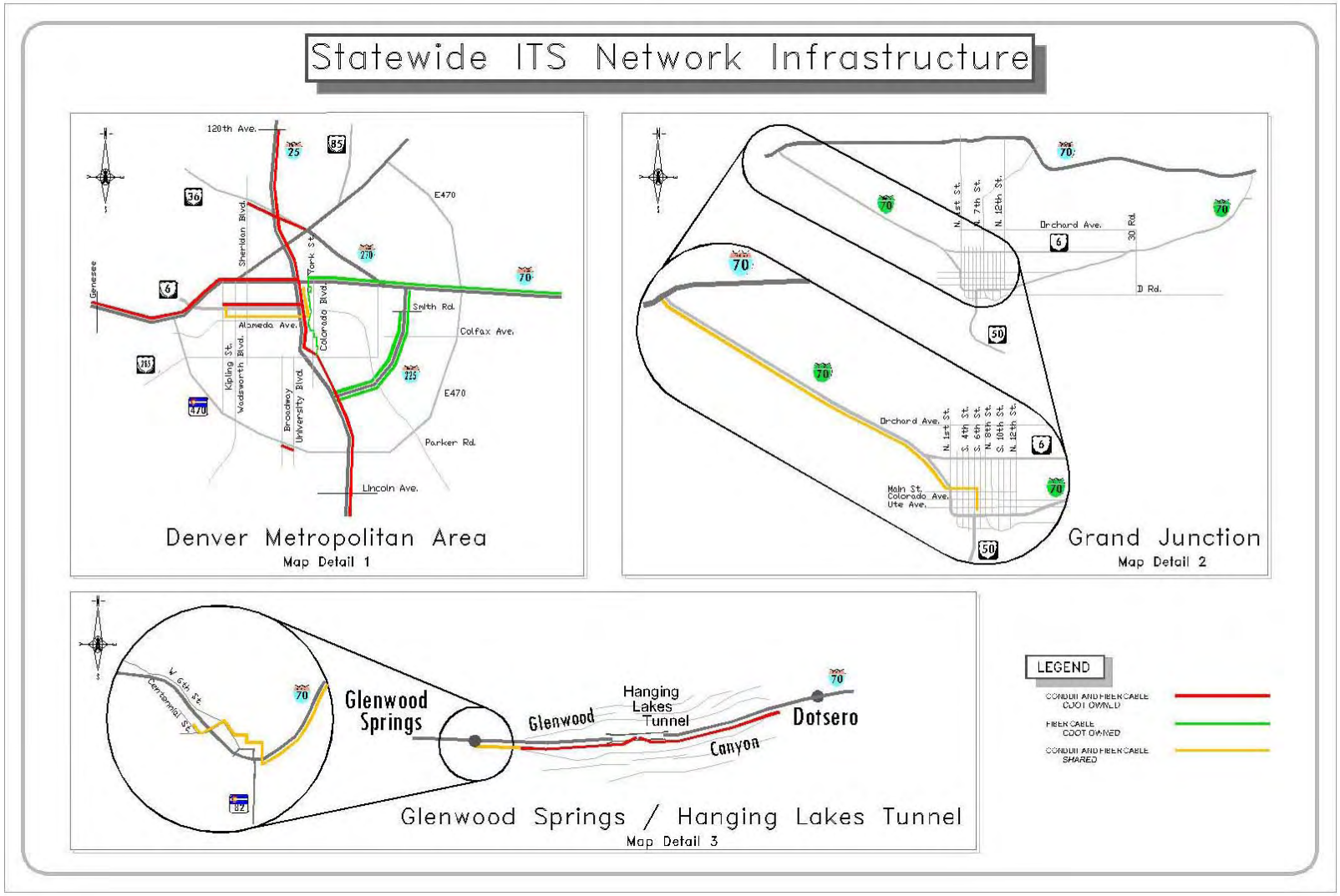


Figure 3. Statewide ITS Fiber Network Infrastructure



Transportation Management Centers

Statewide ITS operations in Colorado are performed through four major centers: the Colorado Transportation Management Center (CTMC) in Golden, the Hanging Lake Tunnel Transportation Management Center (HLT TMC), the Eisenhower/Johnson Tunnel Transportation Management Center (EJT TMC) and the Colorado Springs Transportation Management Center (CS TMC). Also, there are other state and local agency centers that extensively support and assist these major centers.

The CTMC is primarily responsible for providing traveler information, which involves the collection and dissemination of statewide traveler information. In late 2006, CDOT relocated the CTMC from Lakewood to Golden. With this relocation and other fiber projects, the CTMC is now connected to EJT TMC and CS TMC. The CTMC manages an extensive information collection network that consists of: detectors and sensors, CCTV cameras, ramp meters, radar detectors, weather stations, National Weather Service, information toll tag readers, and road condition information provided by Colorado State Patrol (CSP) troopers and CDOT maintenance forces. The CTMC aggregates, analyzes and processes the information and disseminates it via the cotrip.org website, variable message signs (VMS), highway advisory radios (HAR), 511 statewide automated telephone system, broadcast fax, media reports and to Internet-capable cell phones and Personal Digital Assistants (PDA). The CTMC also assists with traffic management, incident management and event management functions working together with the other centers and CDOT regions using ramp meters, HOV lanes, Incident Management Plan strategies and signal timing protocols to improve effective throughput, identify alternative routes and to balance facility demand versus capacity.

The HLT TMC, EJT TMC and CS TMC primarily perform traffic management, incident management and event management functions. These TMCs also assist CTMC in collection and dissemination of traveler information. **Figure 4** shows the coverage areas for traffic and incident management functions that are performed by these TMCs within the state. EJT TMC performs traffic and incident management functions within the Tunnels and on the approaches to the tunnels on I-70.

Fact:
Other prominent centers in Colorado include Office of Emergency Management, Denver TOC, Lakewood TOC, Ft. Collins TOC, Regional Transportation District, Douglas County TOC and Pueblo TOC.

Figure 4. Traffic/Incident Management Services Coverage Areas for Major TMCs

Software System(s)

Colorado Traffic Management System (CTMS) - The ITS infrastructure is controlled and operated by several software systems. In order for these systems to operate in a uniform and consistent manner, they need to be integrated into one overall ITS system. CDOT has developed an integrated statewide system called CTMS. Currently, the CTMS is being utilized to operate variable message signs and traffic cameras. It will be integrated with the Courtesy Patrol system, 511 statewide automated phone system and the broadcast fax service for road and weather condition reports. CTMS utilizes, evaluates and analyzes information that is collected from various devices to address and mitigate freeway incidents and traffic congestion.

Fact:
National studies for typical metropolitan areas show that 50 percent of the capacity of an urban freeway system is lost due to non-reoccurring incidents such as accidents, spilled loads and stalled vehicles.

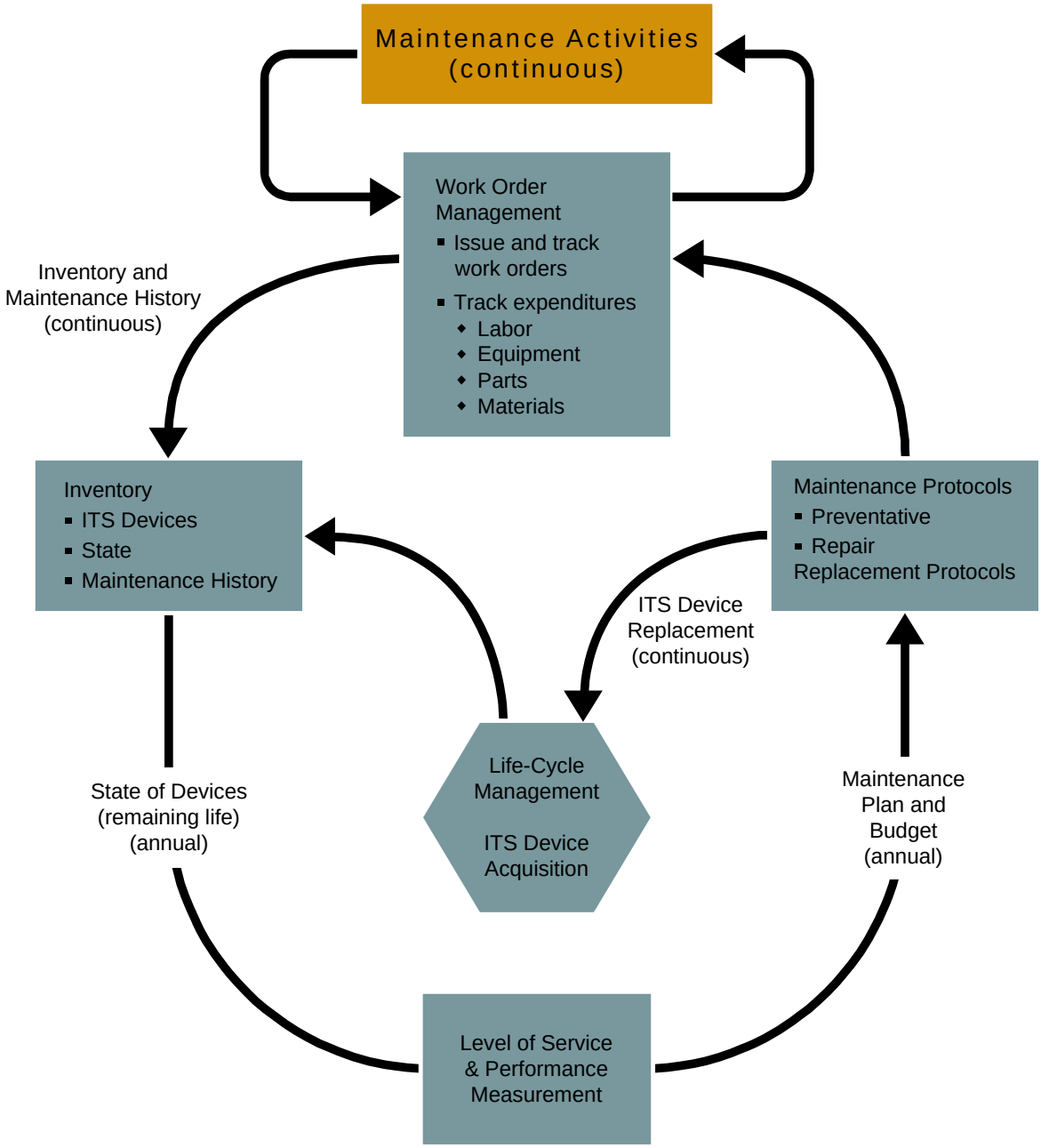
In addition, CTMS is capable of disseminating accurate real-time information about transportation options and conditions to travelers so they can make decisions that facilitate their travel needs. CTMS also supports the travel time application on the I-70 west corridor. Information can be provided to the traveler through dynamic message signs, highway advisory radios, 511 statewide automated phone system, pager and cell phone reports from private partners, websites, kiosks, traffic and weather channels, broadcast faxes and press releases. This allows the travelers to exercise choices concerning their travel from taking alternative forms of travel, modifying travel times and/or routes or choosing not to travel.

ITS Maintenance Management System (ITS MMS) within SAP - As mentioned earlier, CDOT has invested more than $150 million dollars in ITS infrastructure statewide. This infrastructure is predominantly deployed on the state highway system. Until recently, there was not a statewide maintenance system in place to track maintenance and replacement of the ITS infrastructure. As a result, an accurate portrayal of device and system condition and resources needed to properly maintain and replace the ITS infrastructure was not readily available. In addition to resource allocation implications, the ITS infrastructure needs to be properly maintained and operated to support the ITS core services. It is essential that operators and owners of the ITS infrastructure have the proper tools to optimally maintain their infrastructure.

In late 2003, CDOT's ITS Branch, working with stakeholders, developed the framework for the ITS Maintenance Management System (ITS MMS). The framework provided a systematic and consistent approach to address maintenance and replacement needs of the ITS infrastructure. The framework identified the necessary tools for systematic life-cycle management of ITS devices. This includes budgeting, maintenance and replacement protocols, work order management, levels of service and device inventory. The ITS MMS Framework components are described below and illustrated in **Figure 5**.

- **Device Inventory** - provides standardized and current information on the device inventory including standardized business rules for adding and removing devices from the inventory.
- **Maintenance Protocols** - provides standardized CDOT maintenance protocols for each type of ITS device.
- **Replacement Protocols** - includes guidelines for replacements needed to preserve the integrity or enhance the functionality of the ITS system.
- **Level of Service and Performance Measurement** – ITS device and system performance measurement by availability will be derived from the data established through work order management.
- **Work Order Management** - defines the rules to systematically issue work orders when devices require preventative or repair maintenance.
- **Life-cycle Management** - provides all the cost information to manage life-cycle costs of each ITS device.

Figure 5. ITS Maintenance Management System Framework



In 2006, CDOT implemented the ITS MMS Framework into CDOT's SAP system. The system framework will be fully implemented shortly. In conjunction with the SAP implementation, CDOT is conducting an inventory of the ITS infrastructure statewide in order to verify and collect additional device data in accordance with ITS MMS functional requirements. The statewide ITS inventory is nearly complete. This inventory will be available in SAP for ITS, Region's and DTD maintenance staff to perform maintenance activities using a work order based system. This will allow CDOT to track expenditures for labor, materials, equipment, warranties, device life cycles etc., as well as preventative maintenance protocols and cycles and device and system condition.

Maintenance Decision Support System (MDSS) - CDOT is one of eleven participating states in a FHWA sponsored Pooled-Fund Study MDSS implementation. The system allows CDOT to monitor weather and road surface conditions. Based on this information, the system recommends appropriate materials and quantities for roadway treatment. This allows CDOT to manage its resources (staff, equipment and materials) efficiently and effectively. CDOT has deployed the MDSS application on certain roadway segments in all of the CDOT Regions. The majority of the MDSS implementation is focused in Region 4. The MDSS application is proving to be a very useful tool for winter operations mainly snow plowing. CDOT is expanding the MDSS application for non-winter operations such as weed spraying, mowing, lane striping and surface repairs. MDSS road condition information, which is real-time, accurate and pertinent to a specific highway segment is being incorporated into the CTMS system.

Owners

Within Colorado, the ITS infrastructure is primarily deployed by CDOT's ITS Branch, CDOT Regions, Hanging Lake Tunnel, Eisenhower Johnson Tunnel, cities, counties and transit agencies. As a result, the statewide ITS infrastructure is owned by various entities. This infrastructure is primarily being deployed on the state highway system.

Fact:
Within CDOT, all Regions, the major tunnels, Division of Transportation Development and ITS Branch own ITS infrastructure.

Partners

Through partnership agreements with both public and private entities, CDOT has deployed communication infrastructure along several key corridors. On the I-70 west corridor fiber deployment project, partners included CDOT Regions 1 and 3, CDOT ITS, POE, CSP, Breckenridge, Silverthorne, Idaho Springs and Georgetown. On the I-25 south corridor fiber deployment project, partners included CDOT Regions 1 and 2, CDOT ITS, Colorado Higher Education, Colorado Springs TMC and municipal water, and Douglas County. In addition to the current partnerships, CDOT is considering working with other private partners such as Xcel, Comcast etc., in future fiber deployments.

Fact:
Media partners include Denver TV stations (Channel 2, 4, 7, 9 News, Fox News), KOAA (Pueblo), over 10 radio stations across the state and Metro Traffic.

In order to support ITS core services, such as incident management, traffic management and traveler information, support is needed from partner agencies such as: municipalities, police, fire, Colorado State Patrol, emergency management centers, the media, event venues, transit agencies, FHWA, National Park Service, National Weather Service, military bases, etc. These partner agencies allow for sharing of communication infrastructure, traffic and incident information and effective dissemination of information. In the event of a major disaster, it is important for the ITS infrastructure to provide a supporting role in evacuation route assistance and plans.

Fact:
Other State agency partners include Colorado State Patrol, Office of Emergency Management, Department of Revenue and Colorado Tourism.

Users

The users form the most important component of the ITS system. The users include the general traveling public and the owners and partners identified in the previous sections. All users desire a safe, reliable and efficient transportation system that is actively managed in a uniform, consistent and integrated manner.

Fact:
Studies show that for every minute it takes to clear an incident from a freeway, there will be an average of four additional minutes in clearing the queue that has formed behind the stopped vehicles.

ITS Performance Measures

CDOT and other entities are deploying ITS applications to improve the productivity of the transportation system and to provide services that enhance the mobility and safety of Colorado's traveling public. In conjunction with this, it is important to measure the performance and benefits of these ITS applications and solutions to ensure the effectiveness of the application and satisfaction for the transportation system users. A primary outcome of the measures is the ability to compare the benefits and costs of the systems, and to determine which systems have the greatest positive impact to the state. Development of core services level performance measures are useful for decision makers to assist in making decisions regarding continued implementation and support of efficient and effective ITS systems and devices.

Beginning 2001, CDOT's ITS Branch completed the development of ITS performance measures for monitoring the level of service and benefits associated with CDOT's ITS Core Services. Since early 2003, CDOT's ITS Branch has been actively involved in the implementation of the performance measures in the state. In the past, such efforts tended to focus on national statistics and benefits. The latest efforts focus more on Colorado specific impacts of ITS within the state. The data-collection needs for implementing a comprehensive set of overall ITS performance measures exceeds the data-collection capabilities within the state. As a result, the latest efforts focus on measures that are easily achievable and measurable. The ITS Branch is an active member of CDOT System Operations Core Service Action Plan, which has identified several ITS related strategies and goals. The related performance measures in the Plan are listed below:

- Percent of ITS devices meeting the targeted level of service.
- Percent of congested corridors implemented with incident management plans.
- Percent improvement in average response time between CDOT's notification of an incident to on-scene arrival of courtesy patrol.
- Percent of ITS devices implemented in corridors identified in ITS strategic plan.
- Percent of identified congested corridors with ramp metering implemented.
- Percent of identified congested corridors managed by ITS.

In addition to the above measures, CDOT ITS Branch has identified other short-term and long-term performance measures. The following are examples of a few short-term measures:

- Potential number of travelers receiving travel information (use of information, update time, etc.).
- Percent of incidents responded to on managed and non-managed highways.
- Average duration of incidents on managed highways.
- Percent of all road closures due to incidents.

The following are examples of a few long-term measures:

- Number of transportation users using and benefiting from traveler information.
- Customer satisfaction with usefulness of traveler information services.
- Estimated change in throughput of vehicles per hour (over time).
- Estimated peak period incidents, reduced peak period incidents, delay reduction, and fatality reduction.
- Life cycle costs of ITS systems.

As more ITS infrastructure is deployed throughout the state, opportunities exist to insert performance measurement activities with minimal disruption in overall program development. The current plan for developing, implementing, and using the performance measures includes the following steps:

- **Continue to collect initial performance data and establish a baseline**. Establish a baseline of highway operational conditions and performance characteristics before implementation of ITS systems and devices. This information will be used to generate a baseline to benchmark future performance measures and benefits of ITS systems and devices.

Fact:
In a 2004 survey regarding the CDOT Road and Weather Information report via broadcast fax, nearly 75 percent of the respondents indicated that the Report had either a major or large impact on their organization's business decisions and operations.

- **Measure performance of ITS systems and devices on selected high-traffic volume corridors.** Target measurement on the deployment of ITS systems for traveler information, traffic management and incident management on highways with significant traffic flow.

- **Evaluate and compare measures and determine trends.** Evaluate and compare the results of system performance after installation to those measures taken before the systems were installed. Continue monitoring and measuring performance over time to establish performance trends. These performance measures and trends will indicate how and to what extent ITS programs contribute to CDOT investment strategies.

Fact:
A recent CDOT incident management case study indicated there was nearly a 10 percent reduction in traffic at the incident scene due to quick and effective dissemination of incident and road closure information.

- **Measures will be refined and improved.** After collecting data, establishing a baseline from which to benchmark performance, calculating measures and evaluating the trends in performance from that baseline, there will be evaluation of how well the measures themselves are performing. If necessary, measures will be modified or improved.

Fact:
A recent before and after ramp metering study indicated there was over a 40 percent reduction in travel times in the ramp metered segment of I-70 corridor between Idaho Springs and Empire.

NEEDS, FUNDING AND ANTICIPATED REVENUE

The ITS Strategic Plan includes recommendations and outlines resource requirements for implementing Plan actions. There are two major categories that are addressed in the context of resource requirements: 1) Preventative Maintenance and Replacement of Existing ITS Infrastructure; and 2) ITS Statewide Enabling Infrastructure and Statewide Traveler Information Strategic Investments.

Maintenance – Preventative and Replacement

The stakeholders unanimously agreed that preventative maintenance and replacement of existing ITS infrastructure should be the highest priority. This decision was based on the fact that as infrastructure and devices had been and were being deployed; there was not a dedicated source of funds to perform systematic maintenance and replacement of devices. Although the majority of the infrastructure and devices have been installed within the past five to 10 years and are in relatively good condition statewide, it was very evident that the inability to adequately perform maintenance was severely affecting the operational functionality of the devices.

ITS Statewide Enabling Infrastructure

The statewide enabling infrastructure and statewide traveler information is a statewide strategic investment. The statewide enabling infrastructure consists of integrating the CTMC and the TMCs, deployment of fiber optic backbone and high-speed add/drop multiplexers and connection of numerous existing devices to the fiber optic backbone for collecting and disseminating traffic information:

- Completion and full functionality of the CTMC in Golden, the TMCs at Hanging Lake Tunnels, Colorado Springs and Eisenhower Tunnel. The goal is to provide for center-to-center (C2C) connectivity and redundant fail over communication links among the centers. Currently, inter-connectivity exists between CTMC and the CS TMC and EJT TMC. The CTMS operating system software is being installed in the HLT TMC to provide enhanced command and control of devices in the region and interoperability with CTMC and EJT TMC.

- Continued deployment and installation of a long haul high-speed fiber optic backbone and all SONET high-speed equipment necessary for its operation. At the same time as the long haul high-speed fiber backbone is being deployed, CDOT is deploying high-speed add/drop multiplexers at strategic node/concentration points in order to maximize the fiber optic backbone and connect existing devices to the fiber.

- For those areas of the state where fiber will not be available, CDOT ITS is conducting communication needs assessments and pursuing other modes of reliable communication.

- CDOT will plan for and finance the statewide traveler information system as a statewide strategic investment that meets regional and statewide needs. These needs were identified working with multiple stakeholders as CDOT developed ITS Regional Strategic Plans and ITS Architectures for CDOT Regions 1, 2, 3, 4 and 5.

Funding Sources

In the Transportation Commission's Resource Allocation FY 2008 – FY 2035, the ITS Statewide Program is scheduled to receive about $223.0 million (constant dollars). These funds are used for maintenance and operations, limited project development and capital replacement of statewide ITS infrastructure. The ITS Branch maintains all ITS infrastructure and devices on the Front Range, except for the Division of Transportation Development's Automated Traffic Recorders and the Region 6 HOV/HOT system, including statewide weather stations and Weigh-In-Motion systems.

Funding Needed and Deficiency

As with most of the transportation programs, there is a considerable disparity between the amount of resources available and the amount required to meet program needs. **Table 2** shows the ITS Maintenance, Operations, Capital Replacement and Infrastructure needs over a 10-year cycle. A 10-year cycle is chosen to allow for incorporation of new technologies and advancements that could significantly impact the cost of the strategic investments. Also, this allows for the ITS system to reach a certain level of deployment that will enable it to provide significant system functionality at a system-wide level.

Table 2. CDOT ITS Needs (10-Year Cycle)

ITS Maintenance, Operations & Capital Replacement	Dollars
Current Investment	About $8 Million/Year
Maintenance Backlog (over 5 years)	$7.5 Million/Year
Sustain Existing Investment (Future)	$13.6 Million/Year
ITS Infrastructure	**Dollars**
Current Investment	$150 Million
Infrastructure Investment Backlog (over 10 years)	$160 Million
Sustain New Investment (Maintenance, Operations & Capital replacement)	$14.5 Million/Year

Through FY09, the budget for statewide ITS maintenance, operations and capital replacement is about $8.7 million/year. Beginning in FY10, the budget decreases and is not projected to return to the FY09 level until 2032. Nevertheless, the current amount of funding will not be sufficient to sustain the maintenance backlog, which is defined as regular maintenance and replacing existing devices that are past their intended device life. In order to cover this maintenance backlog, about an additional $7.5 million/year is required for the next five years. Following that, nearly $13.6 million per year is needed to sustain the maintenance, operations and capital replacement of the existing infrastructure. This does not include any new infrastructure or added capacity to the roadway system.

The current infrastructure investment is valued at about $150 million dollars. ITS funding received from the Transportation Commission's Resource Allocation can only be used for maintenance and operations and limited project development. The only source for new project investments is using limited federal grant opportunities, state funds, other grants and local

projects. The funding needed for ITS strategic investments is about $160 million over the next 10 years. The funding shown provides for a system that is robust enough to support the infrastructure and devices and deliver improved and enhanced transportation services to the users. It is understood that an investment of this size requires that it be made over a period of time. Also, with the new investment in infrastructure, maintenance, operations and capital replacement for the new investment will be additional $14.5 million/year.

Leveraging of Funds by Working with Partners

Fact:
Communication infrastructure sharing partners include Colorado Higher Education Eastern School District, Colorado School of Mines, Denver, Douglas County, Colorado Springs and others.

As mentioned above, the program needs are considerable. However, by working with numerous and multiple federal, state, local and private partners, the ITS Branch has been able to significantly maximize limited resources, which has resulted in substantial value to the state. This has become a standard operating procedure when a project is being developed, and ITS Branch partners have recognized the benefit as well. For example, on a fiber installation project, another state entity was provided several strands of fiber in exchange for cash and in-kind services such as fiber splicing. A local jurisdiction wanted to place a camera on an arterial that intersected a state highway. The camera image of the state highway was beneficial to the ITS Branch so the ITS Branch purchased the camera and the local jurisdiction installed the pole and connected the camera to its fiber. While the monetary benefit to the state is important, perhaps more important are the relationships that are fostered by working together with partners toward a common goal. This is one very important reason that the ITS Branch has made significant progress over the past few years. CDOT is currently considering working with Xcel and other Utilities, etc on future partnership agreements regarding shared deployment opportunities.

CONCLUSION

As Colorado's population grows, there will be increasing demands placed on its transportation system. Traditional solutions, such as adding more lanes and new roadways, will continue to make only a minimal impact as budgets are limited and costs of construction become more expensive. The state must continue to manage and operate its infrastructure as safely, efficiently and effectively as it can give the funding limitations. This will be possible in part by employing transportation management strategies such as ITS.

Given the CDOTs accomplishments to-date and future deployment guided by strategic plans, ITS remains one of the most low-cost high-benefit management strategies in Colorado that is designed to get the most of the existing transportation system. It will not make the congestion problem disappear. Traditional solutions, such as adding more capacity, may still need to be implemented. However, without the utilization of ITS, there is no doubt the transportation system will get worse and unmanageable. ITS is a valuable management strategy that will assist in a safer, efficient and effective transportation system.