FINAL

City of Centennial

Intelligent Transportation System Master Plan Concept of Operations Report

Prepared for

City of Centennial, Colorado

March 6, 2016

PREPARED BY

CH2M HILL Engineers, Inc.

Contents

Tables

Figure

Acronyms and Abbreviations

AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
BRT	bus rapid transit
C2C	center-to-center
CH2M	CH2M HILL Engineers, Inc.
CCTV	closed-circuit television
CDOT	Colorado Department of Transportation
City	City of Centennial
CONOPS	Concept of Operations
DMS	Dynamic Message Signs
DOW	day of week
DRCOG	Denver Regional Council of Governments
FAST	federal transportation authorization
FHWA	Federal Highway Administration
HOT	high-occupancy toll
HOV	high-occupancy vehicle
I-25	Interstate 25
ICM	Integrated Corridor Management
ITS	Intelligent Transportation System
NIMS	National Incident Management System
MAP-21	MAP-21Moving Ahead for Progress in the 21st Century
PBPD	Performance-Based Practical Design
PTZ	pan-tilt-zoom
Public Works	City of Centennial Public Works Department
RSOG	Regional Signal Operations Group
RTD	Regional Transportation District
RWIS	road weather information system
SHRP2	second Strategic Highway Research Program
TEA-21	Transportation Equity Act for the 21st Century
TMS	Transportation Management System
TOC	Traffic Operations Center
TOD	time of day
TSM&O	Transportation Systems Management and Operations
TSP	transit signal priority
TSSIP	Traffic Signal System Improvement Program
UPS	uninterruptable power supply
USDOT	U.S. Department of Transportation

Concept of Operations Purpose and Scope

The Project Team of the City of Centennial (City), Public Works Department (Public Works) and CH2M HILL Engineers, Inc. (CH2M), working closely with other City representatives, has developed a plan for enhancing and expanding the City's existing traffic signal control system and other Intelligent Transportation System (ITS) components to create an integrated Transportation Management System (TMS) to address most operational needs within the City and achieve the desired goals and objectives. This Concept of Operations (CONOPS) provides a "user-oriented view" of the proposed TMS—including enhancements to existing systems and operations—to be implemented within the city, along with connections to and coordination with other transportation agencies. This CONOPS focuses on those enhancements and functions that should occur within the next five years; but potential concepts and innovative strategies beyond that time period are also addressed.

1.1 Purpose

Developing the CONOPS represents one of first and most important elements of the "systems engineering process." Often depicted as a "V" diagram (Figure 1-1) as a way of relating the different stages in the system life-cycle to one another, systems engineering is a formal process by which quality is continuously promoted. Systems engineering may be described as a "requirements-driven development process;" that is, the user (i.e., stakeholder) needs and requirements are the overriding determinant of the system concept, design, and component selection and implementation. Moreover, applying the systems engineering process is required for most Transportation Systems Management and Operations (TSM&O) and ITS projects that involve federal aid.

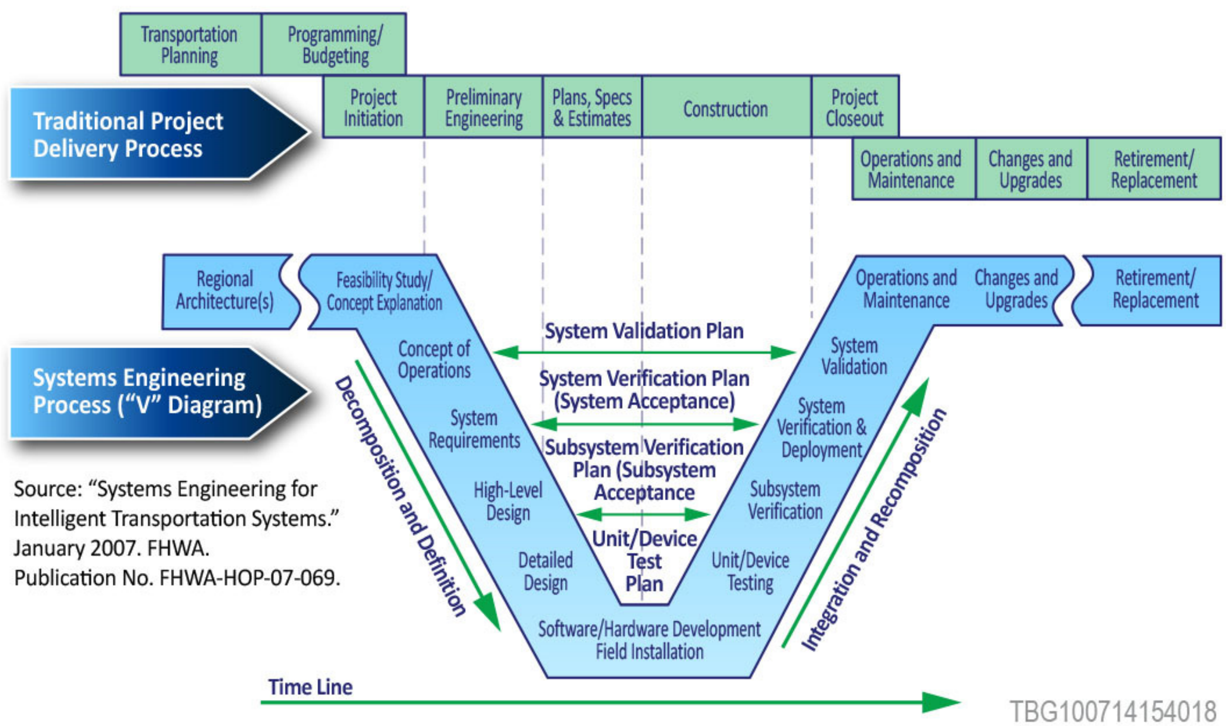

Figure 1-1. Elements of the Systems Engineering Process Diagram

By definition (Federal Highway Administration [FHWA], 2005), a CONOPS does not delve into technology or technical details; rather, it focuses on project area needs and problems, operational goals and objectives, and proposed strategies and integration approaches for meeting the needs and attaining the objectives. The CONOPS also lays the foundation for early agreement among the stakeholders on all system aspects; as such, the CONOPS should be written such that people with a wide range of technical backgrounds may easily understand it.

The American National Standards Institute (ANSI)/American Institute of Aeronautics and Astronautics (AIAA) G-043, *Guide for the Preparation of Operational Concept Documents* (ANSI/AIAA, 1992 and 2012) was used as the basis for developing the Centennial TMS CONOPS. According to these ANSI/AIAA documents, a CONOPS has the following purposes:

- Describe the system characteristics from an operational perspective
- Facilitate understanding of the overall system goals with users, buyer, implementers, architects, testers, and managers
- Form an overall basis for long-range operations planning, and provide guidance for developing subsequent system definition documents, such as system requirements and interface specifications
- Describe the user's organization and mission from an integrated user and system point of view.
- Provide guidance for developing subsequent system definition documents (e.g., master plan, system requirements and specifications), and provide the basis for system validation following implementation

The intended audience of this CONOPS is quite vast and varied—specific stakeholders are identified in a subsequent chapter. This audience includes transportation planners, system operators, system maintainers, system engineers and designers, system implementers and testers, and City administrators and decision-makers. The audience also includes planners and decision-makers in other jurisdictions and organizations who will interface with the proposed system in some manner. As such, the CONOPS must be somewhat all things to all people because the intended audience has a wide range of technical and managerial backgrounds. A good CONOPS should tell a story; that is, it should be a narrative, pictorial description of the system's intended use. This is accomplished by describing the "what, where, when, who, why, and how" of the system operations. These questions are graphically shown in Figure 1-2, and answers are provided throughout the rest of this CONOPS.

1.2 Overview

This section describes the chapters in this CONOPS.

1.2.1 Chapter 1—Concept of Operations Purpose and Scope

Chapter 1 provides an overview of the CONOPS and its purpose. The supporting documents and other resources used in developing the CONOPS are also identified. An executive summary of the proposed systems and operational concepts is also provided.

1.2.2 Chapter 2—Background

Chapter 2 briefly summarizes the current traffic signal control system and associated operations, including the current drawbacks and limitations. A discussion of traffic and safety issues is also presented.

1.2.3 Chapter 3—Operational Needs

Chapter 3 provides an overview of the operational needs in Centennial. The vision, goals, and objectives for the Centennial TMS are then defined.

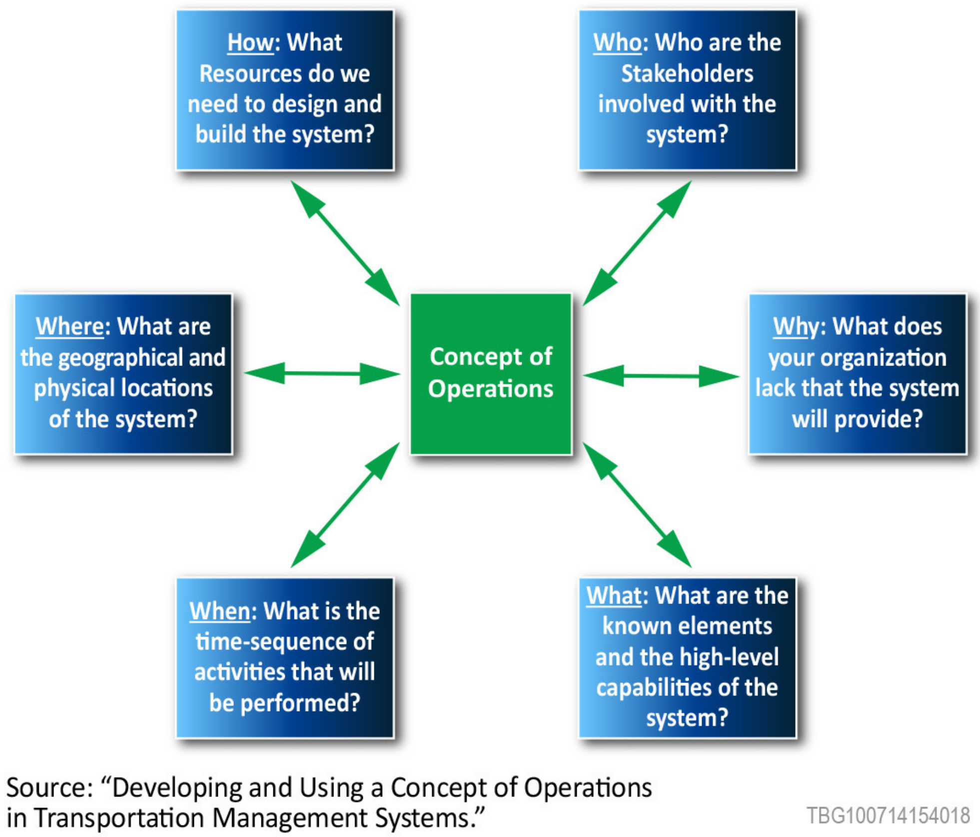

Figure 1-2. Flow Diagram of Major Questions the Concept of Operations Will Answer

1.2.4 Chapter 4—User-Oriented Operational Description

Chapter 4 identifies the various TMS stakeholders and discusses how they use and interact with the system, and with each other.

1.2.5 Chapter 5—System Overview and Concept

Chapter 5 provides an overview of the TMS and the operational enhancements to the current systems, including modes of operation, new capabilities, and interfaces to other systems and organizations. How the recommended TMS helps to achieve the operational objectives and needs are also discussed. Conformity with the regional ITS architecture is also addressed.

1.2.6 Chapter 6—Operational and Support Environment

Chapter 6 describes changes to any additional field components, central hardware and software, and internal and external interfaces to achieve the TMS concept. This chapter also discusses staffing and related operational needs associated with the TMS concept (e.g., Traffic Operations Center [TOC] Plan).

1.2.7 Chapter 7—Operational Scenarios

Chapter 7 contains high-level descriptions of likely operational scenarios associated with the Centennial TMS, including conditions that trigger the scenario, underlying assumptions, TOC operators' responsibilities and actions, and coordination between stakeholders. Scenarios described include off-peak conditions, peak periods, work zones, severe weather, incidents and related nonrecurring congestion, and system failures. The proposed coordination of Arapahoe Road operations is also discussed throughout.

1.2.8 Chapter 8—Summary of Impacts

Chapter 8 discusses potential needs and constraints on developing the recommended TMS. Potential benefits, along with a preliminary list of performance measures, are also presented.

1.3 Referenced Documents

The following documents are referenced in or were otherwise used in developing the CONOPS:

- *Transportation Master Plan*, City of Centennial, adopted December 2013
- *Transportation System Communications Master Plan*, City of Centennial Public Works Department, August 24, 2010
- *Our Voice, Our Vision, Centennial 2030: Community Visioning Process Final Report,* City of Centennial, April 2008 (2008a)
- *Centennial Economic Development Strategic Plan*, City of Centennial, adopted November 3, 2008 (2008b)
- *City of Centennial Fiber Master Plan*, February 2016
- *Traffic Signal System Improvement Program*, Denver Regional Council of Governments (DRCOG), 2013 Update
- *Regional Concept of Transportation Operations*, DRCOG, adopted August 15, 2012
- *Denver Regional Intelligent Transportation Systems Strategic Plan*, DRCOG, adopted December 5, 2007, and amended October 20, 2010
- *Regional ITS Architecture for the Denver Regional Area*, Colorado Department of Transportation (CDOT) and DRCOG, November 2007
- *Systems Engineering Guidebook for ITS,* version 3.0, FHWA, 2009
- *Guide to the Preparation of Operational Concept Documents* ANSI/AIAA-G-043-1992, American Institute of Aeronautics and Astronautics (AIAA) and American National Standards Institute (ANSI) 1992 and updated 2012
- *Developing and Using a Concept of Operations in Transportation Management Systems*, FHWA-HOP-07-001, FHWA, August 2005
- *Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations - A Desk Reference*; FHWA-HOP-10-027, FHWA, April 2010, and the accompanying Guidebook (FHWA-HOP-10-6)
- Documentation from Econolite® regarding the Centennial Existing Traffic Signal Control System (“Centracs”)

Additionally, several meetings and workshops were held with Centennial staff and other stakeholders to discuss the vision, traffic signal control system functions, system goals and objectives, and CONOPS overview.

1.4 Executive Summary

1.4.1 Vision

A vision statement briefly spells out an aspirational description of what the City's enhanced ITS-based TMS will accomplish. As a result of a "visioning session" and subsequent workshop with City staff, the following vision statement was crafted:

> *Centennial's transportation management system will be a major component of an overall "Smart City" approach, using advanced operations strategies and innovative technologies to promote high-levels of mobility, reliability, and safety along the City's transportation network, and providing a positive user experience. The system will be developed and operated in an integrated and sustainable manner, providing resilience and flexibility for the future, thereby supporting a vibrant economy and quality of life for the City's growing population.*

1.4.2 Goals and Objectives

Goals are broad statements that describe a desired end state—what an organization wants to accomplish. Establishing system goals stems from the values inherent in the vision statement, coupled with considering other local and regional transportation management goals to ensure consistency and compatibility. Several goals were developed for the Centennial TMS and subsequently vetted during a stakeholder workshop; these goals are listed and defined in Table 1-1.

Table 1-1. Goals for the Centennial Transportation Management System

- **Mobility—**Help enhance moving people and goods by reducing congestion and recurring delays on the arterial network.
- **Reliability—**Improve the efficiency of the arterial network by reducing non-recurrent delays and increased consistency of travel times from day to day.
- **Safety—**Help significantly reduce crashes, serious injuries, and fatalities, including those of pedestrians and cyclists, on the arterial transportation network.
- **Incident and Event Management—**Minimize the impact of crashes, special events, weather, and other incidents on arterial operations.
- **Environmental—**Help protect and enhance the area environment by reducing emissions and noise from the arterial network and conserving energy.
- **User Experience—**Enhance the experience of all users of the Centennial transportation network by increasing availability and accessibility of information to support better decision-making regarding trips, thereby enhancing users' ability to reach opportunities and activities and generally making their trips better.
- **Integration and Connectivity—**Ensure that the system functions are provided throughout the City in an integrated and multimodal manner and that operations are coordinated with other City agencies—including land use planning and "complete street" initiatives—and with other nearby jurisdictions, transportation and transit entities, and enforcement and emergency service providers.
- **Innovation—**Ensure that all system functions use appropriate and state-of the art technologies and that technologies and operational strategies have flexibility and resiliency in terms of adapting to changing conditions and technology enhancements, while also ensuring that investment decisions for the TMS reflect value.

Objectives are specific, measurable statements of performance that support achieving the goals. Several potential goals were developed for the TMS, focusing on system performance outcomes from the perspective of users, such as levels of congestion, crashes, travel times and delays, travel time reliability, and access to traveler information.

1.4.3 Existing Conditions

The City of Centennial operates and maintains traffic signal hardware at 79 signalized intersections. Currently, approximately 39 of these signals are controlled and coordinated by Econolite® Centracs, located in the TOC at the Public Works offices at 7272 South Eagle Street, Centennial, Colorado. Three different timing plans (i.e., one each for AM peak, PM peak, and off-peak periods) provide signal coordination, with these timing plans being selected on a time-of-day / day-of-week basis. The Centracs system also permits an operator to upload, modify, and download a controller's database, such as timing plan parameters, minimum and maximum green times, and clearance intervals. The remaining signals operate in isolated mode (i.e., no system control), due to a lack of communications—via either fiber-optic cable or wireless—between the intersections and the TOC.

The TOC is not regularly staffed; Centracs is designed for unattended operations. When Traffic Engineering Services staff are notified of a potential hardware or timing issue, they must physically go to the TOC and log onto the signal system to investigate and make appropriate changes to the system operating parameters or contact maintenance services. Because Traffic Engineering Services staff are on a different network from the City network, they have no remote access to the system. As such, they have no other alternative but to be physically present in the TOC to monitor the system and/or to modify any system parameters.

Many signalized intersections along Arapahoe Road—one of the most heavily traveled and congested arterials in the City—are operated by jurisdictions other than Centennial, including CDOT, Greenwood Village, Aurora, and Arapahoe County. Moreover, there are currently no interagency agreements regarding signal operations—including coordination across jurisdictional boundaries—along the Arapahoe Road corridor. Other stakeholders are involved in or influence (i.e., have a "stake" in) operating and managing the Centennial roadway network as summarized in Table 1-2.

Table 1-2. Centennial Transportation Management System Stakeholders

Stakeholder	Traffic Management Activities
Centennial Public Works, Traffic Engineering Services	Operate and maintain traffic signals, system, and other related hardware.
Centennial Public Works, Community Development Services	Provide transportation planning and capital projects development.
Centennial Public Works, other groups	Manage design and construction of capital projects, maintain and repair all City of Centennial streets, and provide snow removal services.
Centennial Innovation Team	Generate innovative responses and develop partnerships to address problems and issues in the City of Centennial, including transportation.
Arapahoe County Police	Respond to incidents and crashes on the arterial network.
Centennial Fire Districts	Coordinate with Traffic Engineering Services regarding fire preemption at selected intersections.
Centennial School Districts	Provide schedules for programing the school beacons.
Arapahoe County	Control and manage selected signals along Arapahoe Road.
Douglas County	Control and manage signals along City of Centennial boundaries.
Greenwood Village	Control and manage selected signals along Arapahoe Road.
Lone Tree	Control and manage signals along City of Centennial boundaries.
CDOT	Control and manage selected signals along Arapahoe Road, manage I-25 and other freeways, manage COTRIP.ORG, and manage regional video sharing.

Table 1-2. Centennial Transportation Management System Stakeholders

Stakeholder	Traffic Management Activities
DRCOG (The designated metropolitan planning organization (MPO) for Centennial)	Provides updated signal timings for major corridors in the City of Centennial once every 3 years, and review and approve requests for capital grants and funding for ITS-related equipment.
RTD	Operate and manage bus, rail, and light-rail transit services in the Denver metropolitan area.

CDOT Colorado Department of Transportation
DRCOG Denver Regional Council of Governments
I-25 Interstate 25
ITS Intelligent Transportation System
RTD Regional Transportation District

Of course, the most important stakeholders are the users of the Centennial transportation network, including drivers, pedestrians, cyclists, and transit riders. Their collective mobility and safety, depends on how well the arterial network is managed and operated.

In addition to the signalized intersections and their operation, and the supporting communications network, additional traffic management hardware and activities include the following:

- **School beacons—**The City operates and maintains school beacon locations at 13 elementary, middle, and high schools in the Littleton and Cherry Creek Public School Districts. None of the more than 30 beacons are connected to a communications network. Accordingly, they must each operate on a time-of-day/day-of-week/yearly schedule using time clocks at each beacon location. The schedule is input at the beginning of each school year based on information provided by the school districts.
- **Weather stations—**Road weather stations are currently operating within the city at four intersections. These stations collect various data—air temperature, relative humidity, road surface temperature and condition (e.g., dry, wet, ice), wind speed, and direction—which are sent via cell modems to a third party that hosts the data. City staff can log onto a website to view the real-time information.
- **Closed-circuit television (CCTV)—**The City currently has no existing CCTV cameras. However, cameras with pan-tilt-zoom (PTZ) capability are scheduled to be deployed at several intersections in 2016. These cameras will be tied into the CDOT "Nicevision" system, thereby allowing video-sharing among Centennial, CDOT, and other agencies (and media) on the system.
- **Traveler information—**The City does not operate any traveler information devices such as dynamic message signs (DMS). The only source of real-time traveler information regarding road and travel conditions for major arterials in Centennial must be obtained from private websites and applications, such as WAZE, Inrix, and Google Maps. The COTRIP.ORG website does not provide any information on Centennial arterials, undoubtedly because of the lack of any system detectors along these roadways to measure traffic flows. That said, CDOT has recently signed an agreement with Inrix to provide this arterial information. Additionally, studies are underway to investigate and identify potential DMS sites along Arapahoe Road and Dry Creek Road near I-25 and the freeway interchanges.

1.4.4 Next Steps—Activities to Achieve the Centennial Transportation Management System Vision and Goals

The City of Centennial has made great strides in TSM&O over the past several years. As described previously, much ITS infrastructure is already in place. That said, several needs were identified for achieving the TMS overall vision and associated goals. Meeting these needs will involve both a geographic expansion and functional enhancements of the City's traffic signal control system plus additional ITS systems. Recommended activities for achieving the TMS vision are summarized in Table 1-3. The "immediate" priorities should be initiated as soon as possible and be completed within one to two years. Activities identified as "near term" should start upon completion of the Immediate Phase, and will require two to three years to complete. Mid-term priorities round out the five-year time frame. These activities and projects will help to shift the operational approach from reactive to a more proactive one, while creating the necessary foundation for an innovative future.

In addition to the activities and projects listed in Table 1-3, longer-term priorities also exist. These potential future enhancements, including the accommodation of connected vehicles and automated vehicles, transit signal priority, and direct control of all the signals along Arapahoe Road —may occur beyond the 5 to 7-year time-frame of the project, but should nevertheless be considered as the other improvements and enhancements are put in place.

Table 1-3. Summary of Activities and Projects to Achieve the Centennial Transportation Management System Vision and Goals

Time Frame	Activities and Projects
Immediate Priority	Update the *Transportation System Communications Master Plan* (City of Centennial, 2010) to reflect the city's recent *Fiber Master Plan* while also identifying approaches for connecting all the signals to the system during this initial phase (i.e., before the city-wide fiber network is completed.) The updated plan should also address the necessary communication links between the TOC and other transportation and enforcement entities.
	Establish communications and connectivity along all major corridors and ITS devices in the City (according to the updated Transportation System Communications Master Plan and the Fiber Master Plan.)
	Integrate all remaining signals into the Centracs signal system, including upgrading signal controllers at several intersections.
	Establish a Regional Signal Operations Group (RSOG) and an Incident Management Task Force to address inter-agency coordination and operations. Also develop agreements with these stakeholders in support of region-wide traveler information, coordinated signal operations across jurisdiction boundaries, coordinated incident notification and response, and regional performance management. Coordinating signal timing and operations along the entire length of Arapahoe Road should be the initial focus of this activity.
	Develop and integrate into the signal system additional timing plans for recurring conditions (e.g., shoulder periods), as well as special timing plans for use during incidents, special events, inclement weather conditions, work zones, and freeway diversions.
	Implement CCTV cameras on all major arterials to provide visual coverage to support incident and event management.
	Implement a document control system to improve and update the documentation of the existing (and future) systems, including what data are available, where housed, and how to access.
	Configure and activate automated alert features of Centracs system, and provide remote access system capabilities for traffic engineering staff.

Table 1-3. Summary of Activities and Projects to Achieve the Centennial Transportation Management System Vision and Goals

Time Frame	Activities and Projects
Near-Term Priority	Complete the communication build out, connecting most if not all of the remaining signals to the City-wide fiber network.
	Formalize the signal coordination, communications, and information sharing with other agencies throughout the region, including the development of business processes, procedures and associated responsibilities in support of cross-jurisdictional signal coordination, incident management, work zone management, road weather management and ICM strategies (e.g., major incident on I-25 resulting in traffic diverting to arterial streets). Address the ability of one agency to assume control of another agency's signals, and under what circumstances and scenarios such control would be permitted.
	Establish communications and connectivity to major stakeholders (e.g., other City departments, adjacent jurisdictions, CDOT, Arapahoe County Sheriff) and their respective transportation management centers. Implement the necessary C2C connections and modify the system software to accommodate these links and regional functions.
	Update remaining signal controllers and upgrade / install UPS at selected intersections
	Establish communications and central control of all school beacons, thereby providing the ability to modify and override the schedule resident at the beacon location from the TOC as may be required due to unforeseen conditions (e.g., later start, early dismissal, closures).
	Implement real-time traffic flow detection (e.g., volumes, speeds, travel times, congestion levels) on major arterials in support of automated selection of timing plans (i.e., "traffic responsive mode"), traveler information, and performance management.
	Install additional CCTV
	Automate the traffic data collection, storage, and processing activities in support of performance management.
	Expand and enhance the TOC facility, including the addition of staff to coordinate operations and monitor the system during peak periods,
Mid-Term Priority	Provide DMS along major arterials, and expand existing Centracs functionality to include DMS control, associated database, and message library. Consider other ways of distributing traveler information (e.g., web, social media, text).
	Implement additional real-time weather and roadway surface condition surveillance along major arterials in support of automated selection of timing plans, traveler information, snow removal operations, and performance management
	Provide additional software functionality including integration of road condition and weather data, and DMS control.
	Update timing plans as may be required.

CHAPTER 2

Background

This chapter briefly summarizes the current traffic signal control systems and associated operations, along with other related TSM&O components. This chapter also briefly describes the current drawbacks and limitations and traffic and safety issues.

2.1 Traffic Signals and Control Systems

The City of Centennial operates and maintains traffic signal hardware at 79 signalized intersections (Figure 2-1). On average, one new signalized intersection is installed each year. Moreover, the *Transportation Master Plan* (City of Centennial, 2013) identifies 11 intersections for future signalization.

Currently, approximately 39 of these signals are controlled and coordinated by Econolite® Centracs, with the remaining signals operating in isolated mode (i.e., no system control). Table 2-1 summarizes the Centracs characteristics.

Table 2-1. Summary of Centennial Existing Traffic Signal Control System

Item/Functionality	Centracs
Controllers	Econolite® ASC/2 and ASC/3
Number of timing plans used	Three (AM peak, PM peak, off peak)
Modes of operation	Time of day and/or day of week, some manual
Communications	Ethernet over fiber-optic cable and wireless (Intuicom® radios) between controllers and central
Local intersection detectors (for actuated control)	Inductance loops and video image detection
System detectors (for measuring traffic flows and speeds between signalized intersections)	None
Signal displays	LED bulbs with colored lenses
Other	Signal preemption (via Opticom™) at signals in the vicinity of fire stations

LED light-emitting diode

The Centracs system communicates with each signalized intersection once every second to ensure all controllers are using a common-time reference and signals are operating with the appropriate timing pattern, as well as to obtain real-time status information regarding the controller and detector hardware. Centracs and communications also permit an operator to upload, modify, and download a controller's database (e.g., timing plan parameters, such as cycle length, offset, splits; minimum and maximum green times; clearance intervals).

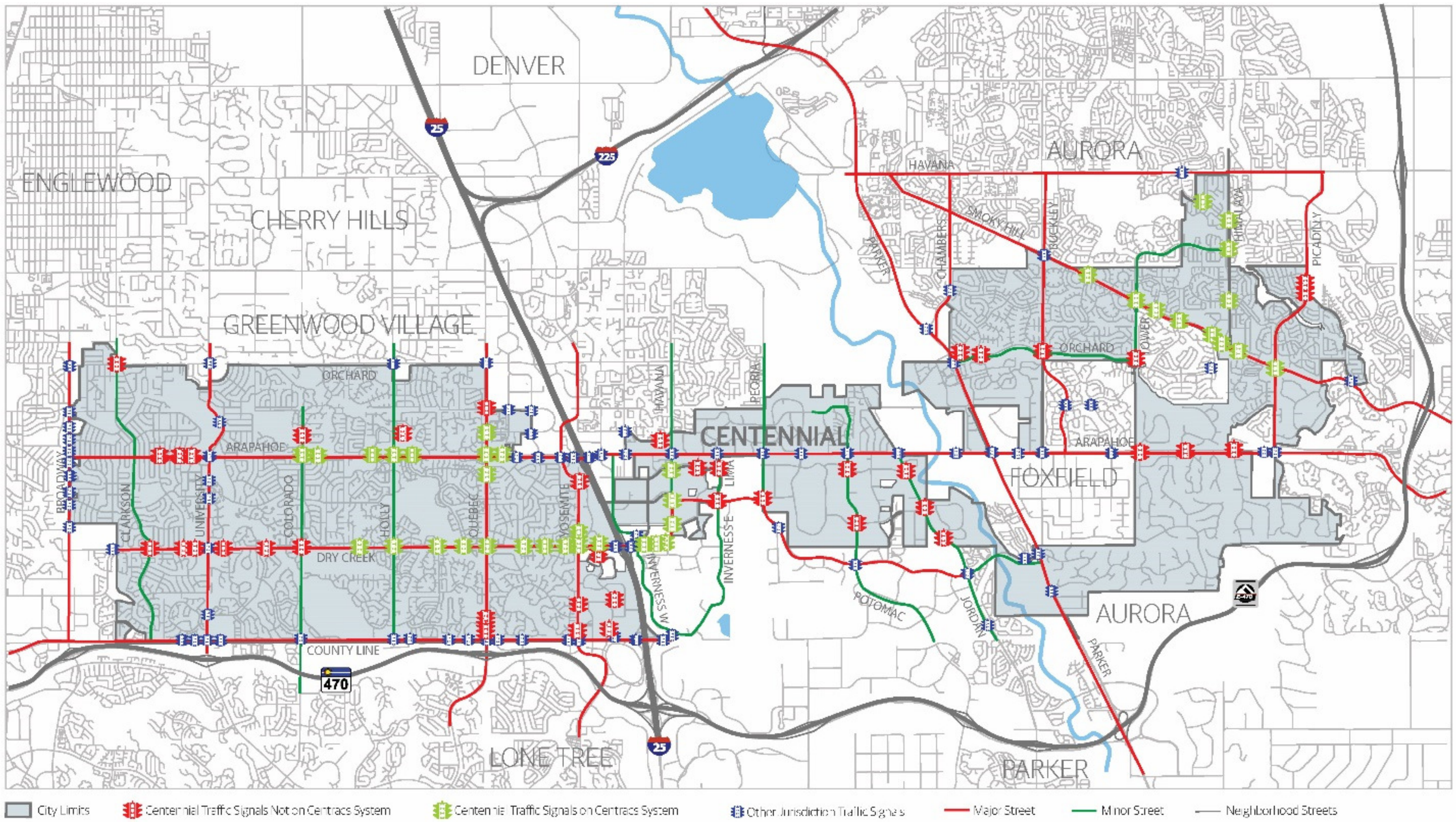

Figure 2-1. Signalized Intersections in Centennial, Colorado

The Centracs system uses a graphical user interface (Figure 2-2), including a city-wide map display for showing status of system intersections and other devices (Figure 2-3). The system and user workstations are located in the TOC at the Public Works facility on Eagle Street. The system also provides numerous reports.

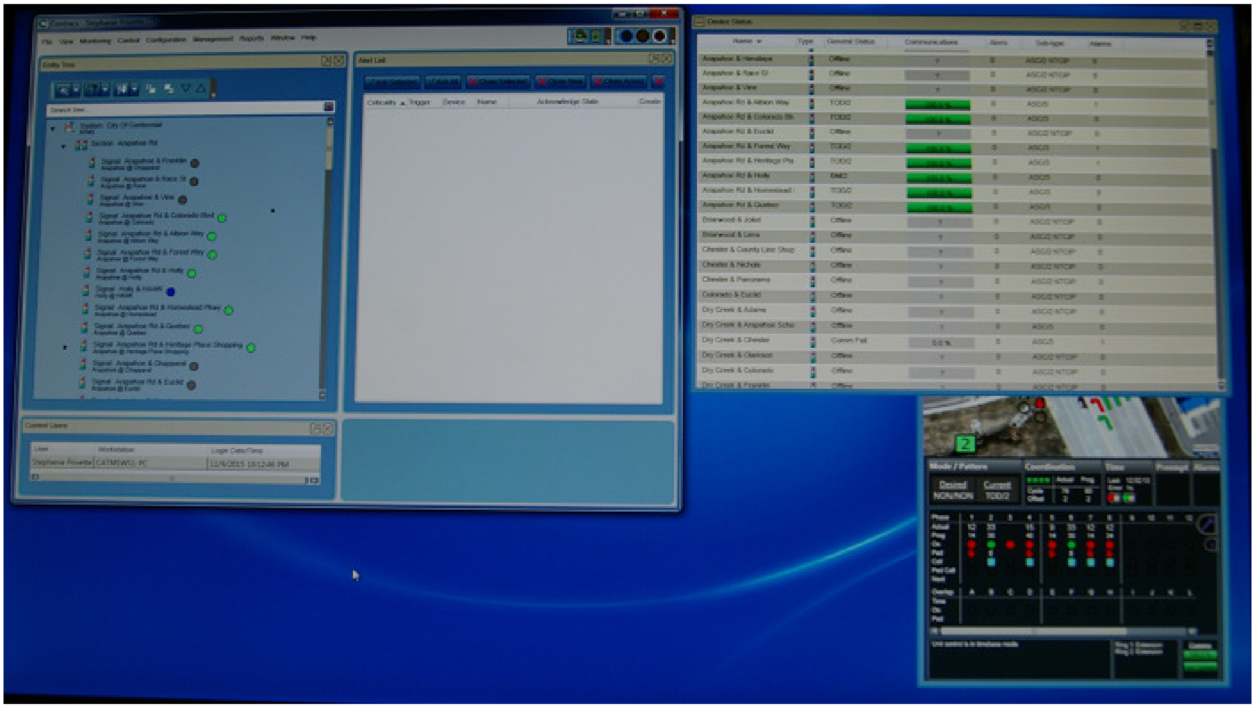

Figure 2-2. Example Centracs Graphical User Interface

Figure 2-3. Centracs Map Display

Centracs has several capabilities that are not currently used, including the following:

- Additional timing plans—up to 64 plans for ASC/2 controllers and 120 for AS/3 controllers (Figure 2-4)—where each plan consists of a cycle length, offset, and a split set
- Traffic responsive selection of timing plans based on real-time traffic parameters (i.e., volumes and occupancy) as collected by system detectors
- Automated problem alerts that can be sent as text messages or emails to staff

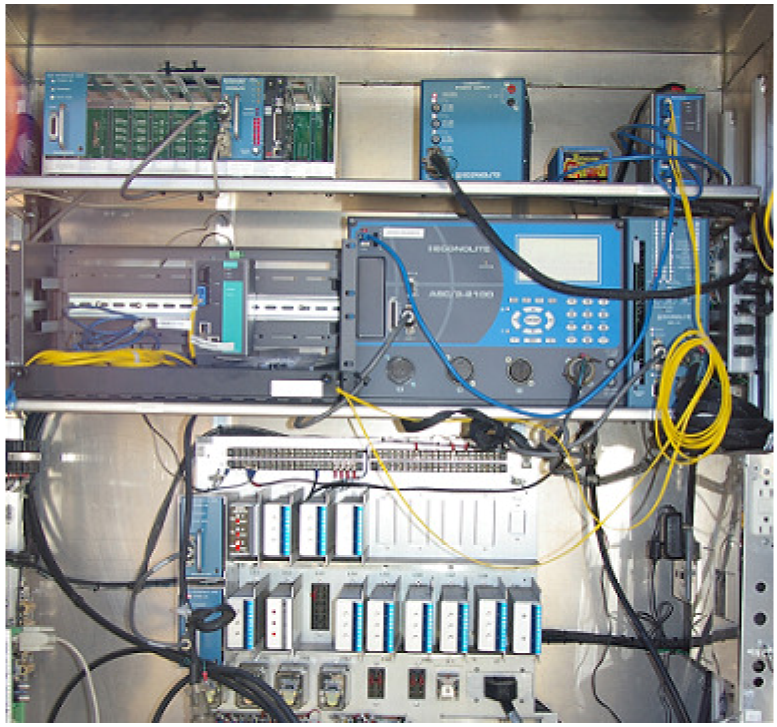

Figure 2-4. Econolite® ASC/3 Controller and Cabinet

In terms of signal timing, approximately every 3 years, the DRCOG completes retiming projects on major regional arterials to improve corridor progression and set consistent timing across jurisdictional boundaries. Many of the City's traffic signals are located on regional corridors controlled by other agencies, with CDOT being responsible for timing on Parker Road (State Highway [SH] 83), Arapahoe Road (SH 88) east of Interstate 25 (I-25), and University (SH 177).

Many signalized intersections along Arapahoe Road—one of the most heavily traveled and congested arterials in the City—are operated by jurisdictions other than Centennial, including CDOT, Greenwood Village, Aurora, and Arapahoe County. Moreover, there are currently no interagency agreements regarding signal operations—including coordination—along the Arapahoe Road corridor.

Figure 2-5. School Beacon

In addition to the aforementioned signalized intersections, the City operates and maintains school beacon locations at 13 elementary, middle, and high schools in the Littleton and Cherry Creek Public School Districts. More than 30 beacons (Figure 2-5) are used, each using light-emitting diode (LED) indications and solar power. No beacons are connected to a communications network; accordingly, they must each operate on a time of day/day of week/yearly schedule each using RTC AP22 branded time clocks at each beacon location. The schedule is input at the beginning of each school year based on information provided by the two school districts.

2.2 Other Field Devices

Several other types of field devices, including the following, are installed (or soon will be) along the City streets to help manage traffic:

- **Detection—**The only detection is at signalized intersections for actuated control (e.g., letting the controller know that a car is waiting on a side-street approach). No system detection is in place for measuring volumes, congestion levels, or speeds between intersections—information that can be used for the automated selection of timing plans, traveler information, and performance measures. Funding has been requested to install such detection devices along Arapahoe Road, Dry Creek Road, and Smoky Hill Road.
- **Weather stations—**Four road weather stations are currently operating within the city at the following intersections: Jordan Road and Fremont Drive, Arapahoe Road and Vine Street, Quebec Street and Costilla Avenue, and County Line Road and Chester Street. The hardware—which is owned by the City—is mounted on traffic signal poles. Weather data—such as air temperature, relative humidity, road surface temperature and condition (e.g., dry, wet, ice), wind speed and direction—are sent via cell modems to Vaisala®, who hosts the data. City staff can log onto a Vaisala® website to view the real-time information (as shown in Figure 2-6).

Figure 2-6. Vaisala® Weather and Roadway Condition Display

- **CCTV—** The City currently has no existing CCTV cameras. However, cameras with PTZ capability are scheduled to be deployed at the following intersections in 2016:
  - Dry Creek Road and Inverness Drive West/Clinton Street
  - Dry Creek Road and Inverness Drive East
  - Havana Street and Geddes Avenue
  - Havana Street and Easter Avenue
  - Havana Street and Briarwood Avenue
  - Easter Avenue and Lima Street

These and other cameras planned for installation will be tied into the CDOT “Nicevision” system, thereby allowing video-sharing among Centennial, CDOT, and other agencies (and media) on the system. The CCTV video displays and PTZ operations will be separate from the Centracs system.

2.3 Traveler Information

The City does not operate any traveler information devices such as DMS. The only source of real-time traveler information regarding road and travel conditions for major arterials in Centennial must be obtained from private websites and applications, such as WAZE®, Inrix®, and Google Maps®. The

COTRIP.ORG website does not provide any information on Centennial arterials, undoubtedly because of the lack of any system detectors along these roadways.[1] That said, CDOT has recently signed an agreement with Inrix to provide this arterial information. Additionally, studies are underway to investigate and identify potential DMS sites along Arapahoe Road and Dry Creek Road in the vicinity of I-25 and the freeway interchanges.

2.4 Communications

The *Transportation System Communications Master Plan* (City of Centennial, 2010) describes a series of prioritized projects to construct an extensive fiber-optic network coupled with radio communications. Because of colocation opportunities, utility companies have been systematically installing fiber-optic facilities in new conduit as roadway improvement projects are constructed. These colocation opportunities have created a conduit network at a low cost to the City. City projects and DRCOG grants have also been used to create a fiber-optic network for the signal system. Centennial fiber-optic communication lines are now present on Arapahoe Road, Dry Creek Road, Buckley Road, Smoky Hill Road, Easter Avenue, Peoria Street, and Jordan Road (Figure 2-7). That said, due to the segmental and opportunistic approach for creating and expanding the network—including connections to traffic signal controllers—no complete physical or logical redundancy is yet available. Where fiber-optic connectivity is not available, the City relies on high-speed wireless radios to communicate with traffic signals remotely from the TOC.

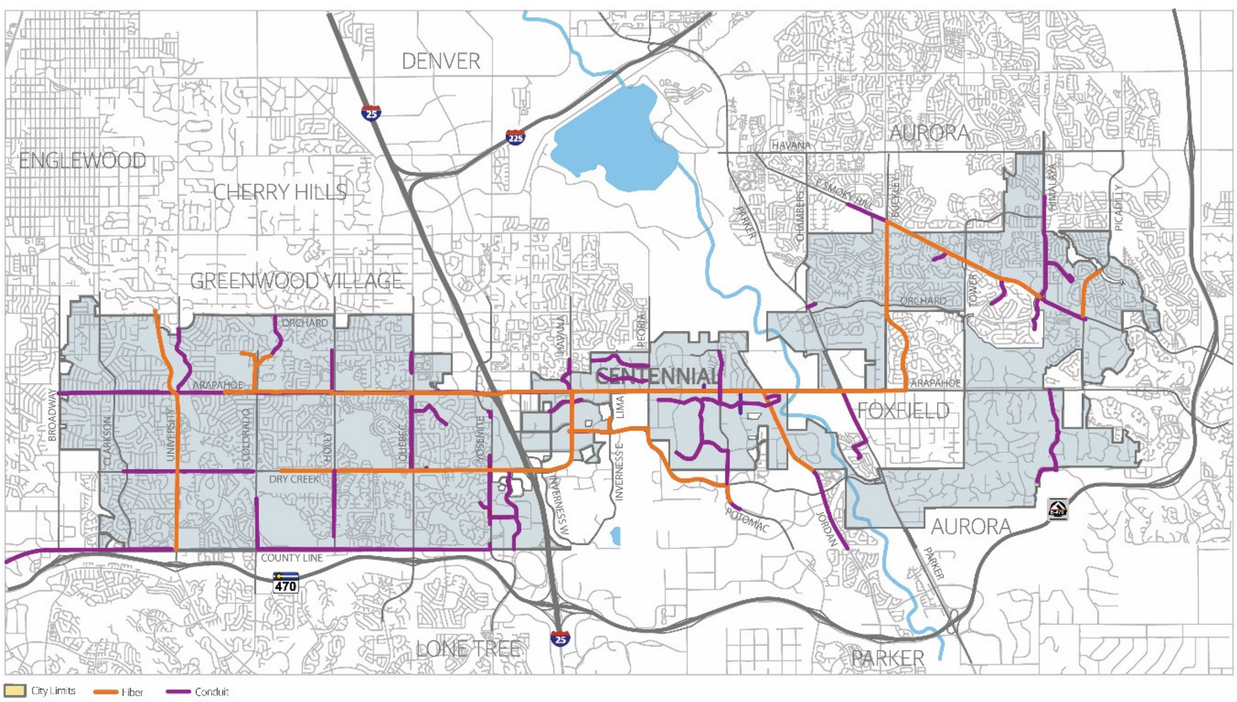

Figure 2-7. Fiber-Optics Communications Network

Centennial recently developed a comprehensive Fiber Master Plan for expanding Centennial's foundational fiber network to support current and future municipal and community needs. As noted in the plan's introduction:

> *"These (fiber) networks are becoming increasingly important to cope with the rapid growth in connected devices, from utility assets, to street lights, to traffic signals, to surveillance cameras.*

[1] Private traveler information providers rely mostly on probe data.

> *Cities that maintain these networks are able to accommodate these "smart city" technologies that make them more efficient, reduce costs, increase the value they deliver to their constituents, and control their own destinies around these key issues."*

The Fiber Master Plan addresses the communication needs for the traffic signal system and other ITS devices that would become part of the integrated TMS.

2.5 Traffic Operations Center

The City maintains and operates a TOC at the Public Works offices at 7272 South Eagle Street in Centennial. The main room of the TOC (Figure 2-8) has two operator workstations. A video wall has six large monitors, each of which can display the workstation information (e.g., real-time map) and any future camera feeds. An adjacent conference room is separated from the main room of the TOC by a glass window wall.

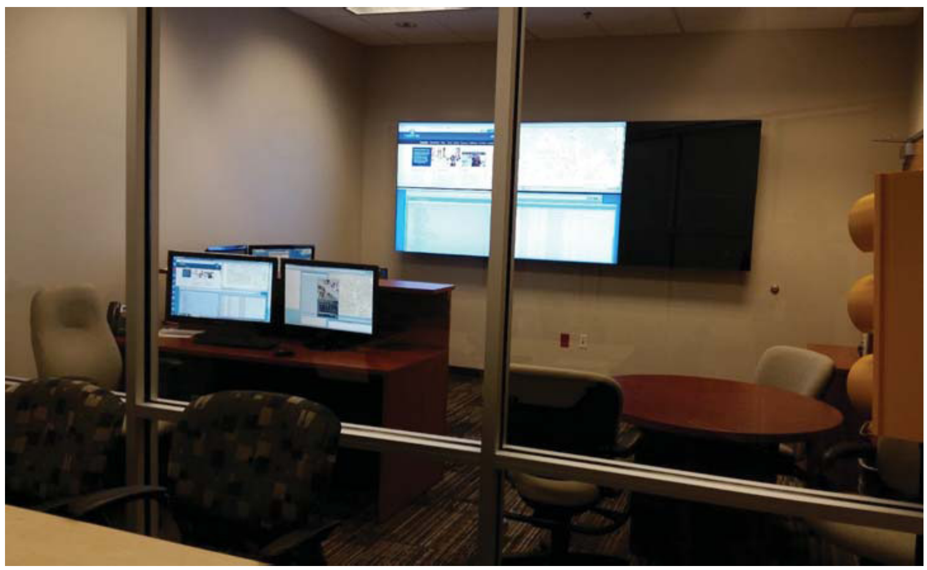

Figure 2-8. Centennial Traffic Operations Center

The TOC is not regularly staffed; Centracs is designed for unattended operations. When Traffic Engineering Services staff are notified of a potential hardware or timing issue, they will go to the TOC and log onto the signal system to investigate. Because Traffic Engineering Services staff are on a different network from the City network, they have no remote access to the system. As such, they have no other alternative but to be physically present in the TOC to monitor the system and/or to modify any system parameters. Moreover, the automated alert capability of Centracs—including notifications via text and email—has not been configured.[2] Signal hardware at the intersections is maintained under a maintenance contract with WL Contractors. Centracs, including software updates, is maintained under a contract with Econolite®.

2.6 Street Lighting

While not part of the TMS or associated ITS components, per se, another important component of managing the arterial street network is street lighting. The street lights are owned and maintained—including the process for reporting and subsequently responding to street light outages—by Xcel Energy. Centennial pays Xcel Energy for these services, as well as the associated power costs.

[2] Alert notifications can be configured by the user in three priority levels – informational (low priority), warning (medium priority), and critical (high priority) – for the system and for any device.

2.7 Drawbacks and Limitations

The City of Centennial has made great strides in TSM&O over the past several years. As previously discussed, much ITS infrastructure is already in place, none of which is identified in the latest version of the Denver Regional ITS Architecture for the simple reason that in 2007—the date of the current Regional ITS Architecture document—none of these elements or components existed. That said, the following are some drawbacks and limitations (in no particular priority):

- Not all the signals in Centennial have been connected to the Centracs system in part because the planned fiber network is still being installed. This minimizes the level of coordination for these non-connected signals. And while some of these signals are located such that coordination with other signals may not be necessary, the ability to monitor the operation of the signals in real time and to modify signal timings is an important consideration.
- The system operates with only three timing plans (i.e., AM peak, PM, peak, off peak), which are selected solely on a time-of-day/day-of-week basis. Additional timing plans for other times of the day (e.g., shoulder periods just before and after peaks) and special operating conditions (e.g., inclement weather, major incidents and diversions), coupled with a more automated selection and implementation of the available timing plans, will likely improve operations throughout the Centennial transportation network. Moreover, given the rapid growth of Centennial and surrounding jurisdictions, more frequent updating of the timing plans is another consideration.
- While the current Centracs system is designed for unattended operation, providing automated alerts for system problems, coupled with remote access capability for traffic engineering services staff, would enhance overall operations and response. Moreover, as the current system is expanded and additional functions and capabilities are integrated together to create a TMS—as subsequently described herein—TOC staffing during peak periods and other times (e.g., emergencies) will likely prove beneficial.
- Practically no real-time information regarding traffic flows (e.g., volumes, speeds) is available via system detectors, nor are CCTV images to monitor roadway or signal operations, including verifying crashes and other incidents that impact traffic flow. This lack of real-time information negatively impacts the availability of traveler information and the ability to change timing plans—often automatically—in response to unplanned variations in traffic flows. This lack of information also limits the City's ability to monitor system performance, as well of that of overall transportation network operations. That said, the City recently submitted a grant request to DRCOG for Traffic Signal System Improvement Program (TSSIP) funding. The City plans to use this funding to install CCTV cameras with PTZ, microwave detectors, Bluetooth readers, and associated fiber and wireless connections to improve vehicle and travel-time monitoring. These devices will be installed along Arapahoe, Dry Creek, and Smoky Hill Roads (Figure 2-9).

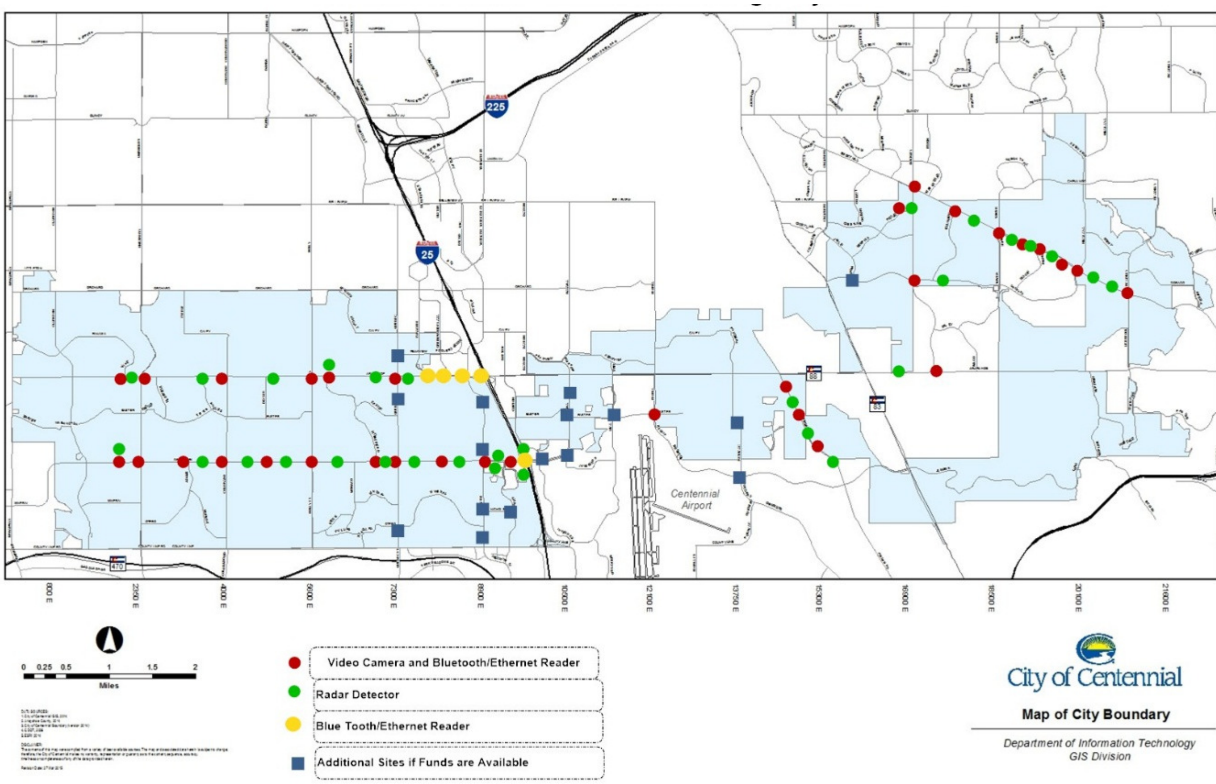

Figure 2-9. 2015 to 2016 Traffic Signal System Improvement Program Vehicle Monitoring Project

- Inclement weather (e.g., snow, ice, thunderstorms) can significantly impact traffic flow and operations, typically resulting in slower speeds by drivers to compensate for slick conditions and/or reduced visibility. As previously noted, only four weather stations exist, and data are not integrated into the traffic signal system (i.e., an operator must log onto a separate website). Additional weather stations and data (e.g., visibility, which is not currently provided) could be used to support automatic selection of weather-related timing plans. The additional information could also be used to plan and manage snow-removal operations.
- A lack of documentation (and/or perhaps a problem with locating information that is available) appears to exist regarding the system assets, communications network architecture and connections, and various maintenance contracts. These gaps can result in inefficiencies when problems arise or when the system is expanded.
- School beacons cannot be monitored or controlled from the TOC—scenario that might be very useful if and when the school opening and closing times are changed (e.g., late start, early dismissal, closed) due to weather or other unforeseen conditions. As previously noted, the City has purchased radios and antennas to create a communication network for school beacons; however, the method for remotely controlling or changing the beacon schedules has not been defined.
- Arapahoe Road (SH 88, Figure 2-10) may be the most important thoroughfare within the City. As shown in Figure 2-11, Arapahoe Road between I-25 and Parker is one of the most congested segments in the City (in terms a volume-to-capacity ratio being greater than one). Additionally, in terms of the number of crashes, nearly half of the top 25 intersections are on Arapahoe Road (Figure 2-12). However, as previously noted, signals along this critical stretch of roadway are operated by five different jurisdictions (including the City of Centennial), with no interagency agreements or C2C communications in place for coordinating operations between these agencies or for coordinated incident management.

Identifying operational strategies and related approaches for overcoming these current limitations and meeting other needs and objectives (as discussed in Chapter 3) is the purpose of this CONOPS and the subsequent Implementation Plan.

Figure 2-10. Arapahoe Road

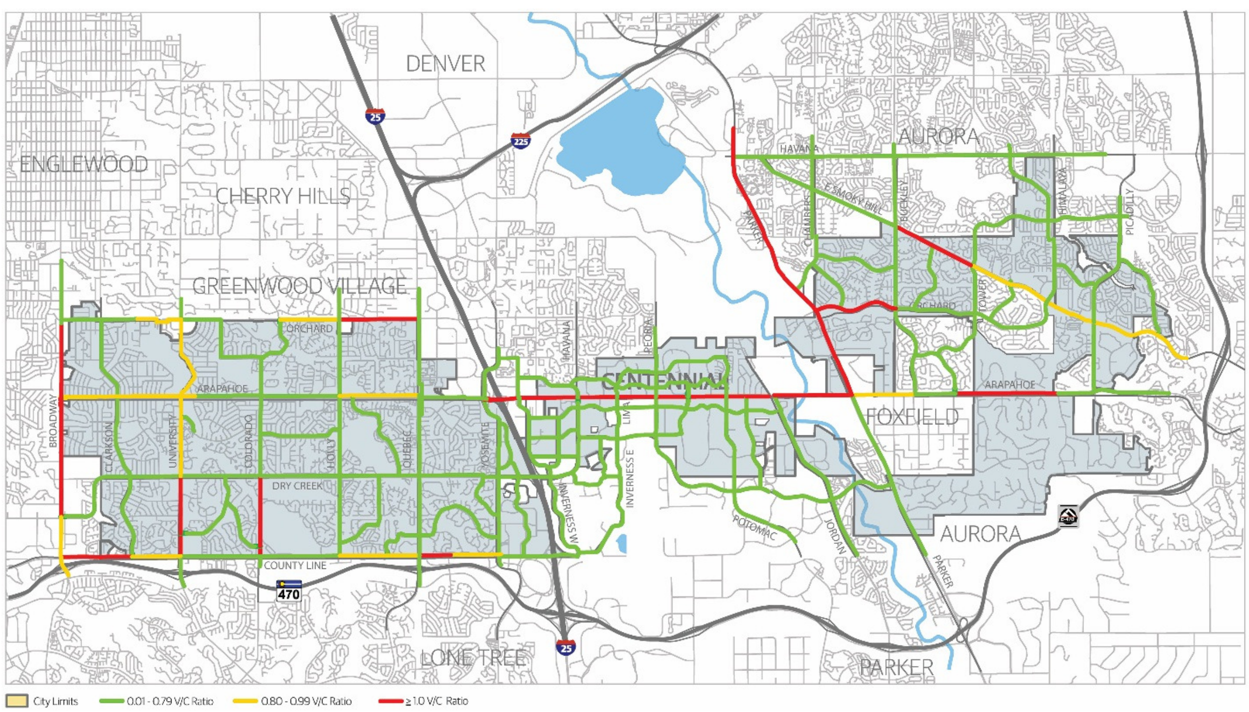

Figure 2-11. Congestion Levels in Centennial

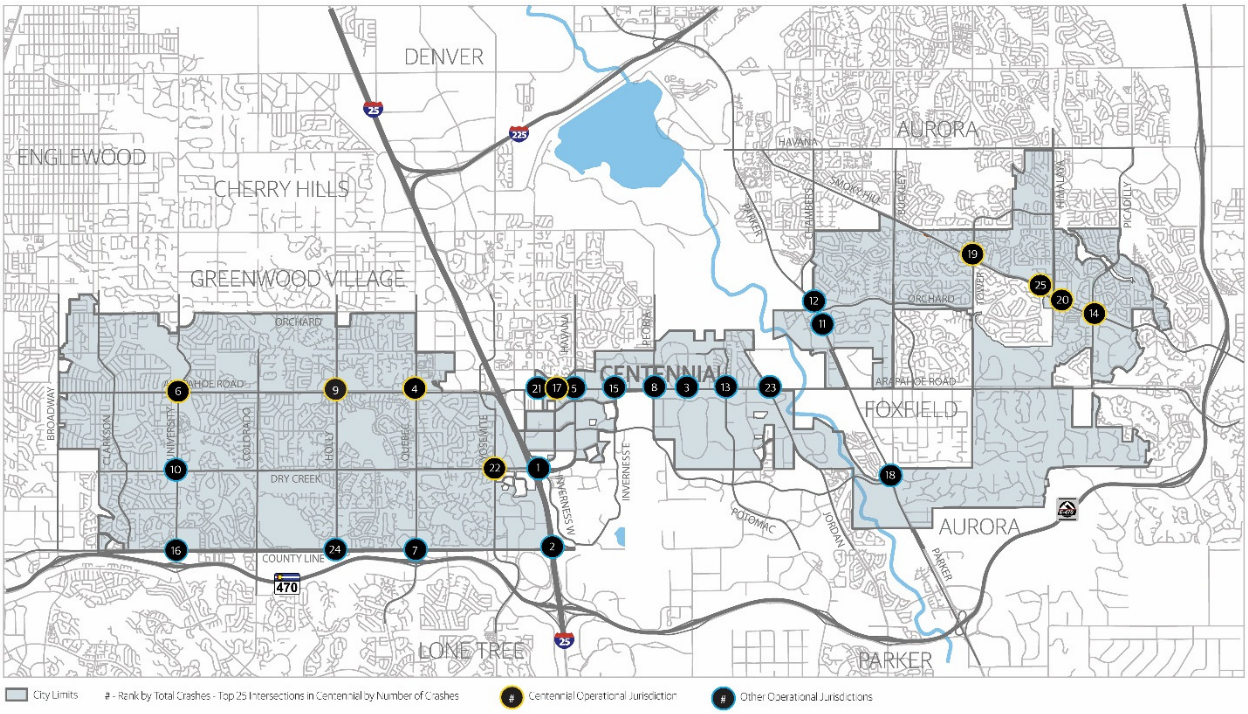

Figure 2-12. High-Crash Intersections in Centennial

CHAPTER 3

Operational Needs, Vision, and Goals

This chapter provides an overview of the operational needs in Centennial. The vision, goals, and objectives for the Centennial TMS are also defined.

3.1 Needs

The last chapter concluded with a list of limitations of the existing traffic signal control system in Centennial. These "needs" and others were discussed with stakeholders at a workshop resulting in the prioritized list of operational needs as summarized in Table 3-1. These priorities were taken into consideration when developing the phased Implementation Plan for the TMS, recognizing that some items must be completed prior to other items (e.g., one cannot implement innovative approaches until the foundational needs – as discussed herein – are addressed resulting in an integrated TMS) and budgets will likely not permit every need to be addressed in the first few years.

Table 3-1. Summary of Transportation System Operational Needs

<table>
<tr><th></th><th>Operational Need</th></tr>
<tr><td rowspan="10">Highest Priority</td><td>Update the Transportation System Communications Master Plan (City of Centennial, 2010) to reflect the city's recent Fiber Master Plan while also identifying approaches for connecting all the signals to the system during this initial phase (i.e., likely before the city-wide fiber network is completed. The updated plan should also address the necessary communication links between the TOC and other transportation and enforcement entities.</td></tr>
<tr><td>Establish communications and connectivity along all major corridors and ITS devices in the City (according to the updated Transportation System Communications Master Plan and the Fiber Master Plan.</td></tr>
<tr><td>Integrate all signals into the Centracs signal system.</td></tr>
<tr><td>Increase the number of connections and associated agreements between the Centennial TMS and other City departments (e.g., sharing video with the County police), and with other jurisdictions and their respective transportation management centers in support of region-wide traveler information, coordinated operations and incident management, and regional performance management. Coordinating the signal timing and operations along the entire length of Arapahoe Road should be the initial focus of this activity, including connections and agreements with CDOT, Greenwood Village, and Arapahoe County.</td></tr>
<tr><td>Expand real-time traffic flow detection (e.g., volumes, speeds, and congestion levels) on major arterials to support signal coordination, automated selection of timing plans, traveler information, and performance management.</td></tr>
<tr><td>Automate traffic data collection, storage, and processing activities (e.g., ADT, congestion and reliability indices, travel times, other performance measures).</td></tr>
<tr><td>Implement CCTV cameras on all major arterials to provide visual coverage to support incident and event management.</td></tr>
<tr><td>Develop and integrate into the signal system additional timing plans for recurring conditions (e.g., shoulder periods) as well as special timing plans for use during incidents, special events, inclement weather conditions, work zones and diversions from the freeways.</td></tr>
<tr><td>Shift the operational approach from reactive to more proactive, including automated selection of the expanded number of timing plans based on real-time traffic flow information and/or weather and roadway surface condition data.</td></tr>
<tr><td>Configure and activate the automated alert features of the Centracs system and provide remote access system capabilities for traffic engineering staff.</td></tr>
</table>

Table 3-1. Summary of Transportation System Operational Needs

	Operational Need
Medium Priority	Implement a document control system to improve and update documentation of the existing (and future) systems, including what data are available, where housed, and how to access. Implement an associated Asset Management System for all ITS and TMS-related devices and software.
	Establish communications and central control of all school beacons.
	Provide DMS along major arterials plus other means (e.g., web, social media, texts) for distributing traveler information regarding traffic conditions in Centennial and beyond.
	Staff the TOC during peak periods and emergencies (e.g., major incidents, weather).
	Formalize signal coordination, communications, and information sharing with other agencies throughout the region, including the development of business processes, procedures and associated responsibilities in support incident management, work zone management, road weather management and Integrated Corridor Management strategies (e.g., major incident on I-25 resulting in traffic diverting to arterial streets). Address the ability of one agency to assume control of another agency's signals, and under what circumstances and scenarios such control would be permitted.
	Implement real-time weather and roadway condition surveillance along major arterials to support automated selection of timing plans, traveler information, snow removal operations, and performance management.
	Replace existing ASC controllers with the new "Cobalt" controller, thereby providing greater capability for future innovative applications such as Connected Vehicles.
	Install UPS at critical signalized intersections in the City, including the ability to monitor the UPS and automated notifications of UPS events (e.g., power failure, low battery, UPS failure).
Lower Priority	Implement TSP along selected corridors in support of enhanced bus operations.
	Improve operations via HOV and/or HOT incentives.
	Consider putting operational control of Arapahoe Road under a single jurisdiction and TMS (i.e., Centennial), coordinating with the other involved jurisdictions.
	Identify potential changes to arterial operations and TMS capabilities in response to on-going innovations such as connected vehicles and automated vehicles.

C2C center-to-center
CCTV closed-circuit television
CDOT Colorado Department of Transportation
DMS dynamic message signs
HOT high-occupancy toll
HOV high-occupancy vehicle
I-25 Interstate 25
ICM Integrated Corridor Management
ITS Intelligent Transportation System
TMS Transportation Management System
TOC Traffic Operations Center
TSP traffic signal priority
UPS uninterruptable power supply

This list aligns quite well—with just a few difference in priorities—with the "ITS Investment Hierarchy for Arterial Networks" as identified in the *Denver Regional Intelligent Transportation Systems Strategic Plan* (DRCOG, 2007), which identifies surface street control for the entire signalized network as the first-level priority; network surveillance, regional traffic control, incident management, and traveler information as the second-level priority; and traffic information dissemination, high-occupancy vehicle (HOV) lane management, and transit signal priority (TSP) as lower-level priorities.

Several items identified in Table 3-1 have a regional context that go well beyond the boundaries of Centennial. Providing coordinated signal timing and operations along the entire length of Arapahoe Road is just one example. Another example is traveler information. The Centennial stakeholders realize that for any traveler information to be of the greatest value, it must be provided on a region-wide basis covering all routes and modes. After all, travelers generally do not care who owns the facility they are using, and they are typically heading to a destination located in another jurisdiction.

ICM Approaches and Example Strategies

- Promote Information Sharing and Distribution (e.g., regional traveler information, DMS owned and operated by Centennial being used to describe current operational conditions on I-25)
- Improve Operational Efficiency of Network Junctions (e.g., coordinated signal timing across jurisdictional boundaries, TSP)
- Accommodate/Promote Cross-Network Route and Modal Shifts (e.g., modify arterial signal timing to accommodate traffic diverting from the freeway)
- Manage Capacity-Demand Relationship within the Corridor (e.g., dynamic speed limits based on congestion and weather conditions, converting regular lanes to transit only).

Many of these regional concepts and operational strategies are addressed by Integrated Corridor Management (ICM). ICM consists of the operational coordination of multiple transportation networks and cross-network connections comprising a corridor on an ongoing and regular basis. In 2006, the U.S. Department of Transportation (USDOT), a joint effort of Federal Highway Administration (FHWA) and the Federal Transit Administration initiated the ICM initiative with the expectation that "corridors offer an opportunity to operate and optimize the entire system as opposed to the individual networks." ICM involves numerous approaches and strategies (see textbox to right), many of which are—or will be in the future—applicable to several of the corridors within Centennial, including Arapahoe Road and I-25 (which includes the parallel arterials of Yosemite and Inverness).

The aforementioned *Denver Regional Intelligent Transportation Systems Strategic Plan* (DRCOG, 2007) identifies four high-priority service areas (see textbox to left) to focus the deployment of ITS in the region (along with an additional five services). Achieving these regional services will require a significant amount of information to be collected by the various jurisdictions in the region and then shared with other jurisdictions as shown in Figure 3-1. The priority needs identified for Centennial fully support this regional view. The discussion of needs with Centennial stakeholders identified the following additional concepts that go beyond the 5-year time frame of the Centennial TMS CONOPS and Implementation Plan:

High-Priority Service Areas from *Denver Regional Intelligent Transportation Systems Strategic Plan*

- Regional Traveler information
- Regional Transportation Operations and Management
- Regional Traffic Incident Management
- Transit Operations and Management

Source: DRCOG, 2007)

- ***"City vision for design, purpose, and integrated planning"—***This concept goes beyond what an enhanced traffic signal system can accomplish. That said, FHWA is currently providing guidance, delivering technical assistance, and sharing resources related to "performance-based practical design" (PBPD). PBPD encourages evaluating the performance impacts of highway design decisions relative to the cost of providing various design features. PBPD can be articulated as modifying a traditional design approach from a "top-down," standards-first approach to a "design-up" approach, where transportation decision-makers exercise engineering judgment to build up improvements from existing conditions to meet both project and system objectives. PBPD uses appropriate performance-analysis tools and considers both short- and long-term project and system goals while addressing project purpose and need. The FHWA Office of Operations supports the overall PBPD effort by highlighting the role TSM&O alternatives and analysis tools can play in supporting PBPD (e.g., implementing operations strategies to help defer costly roadway widening, using strategies to support design exceptions). This approach should be used for all City transportation improvements.

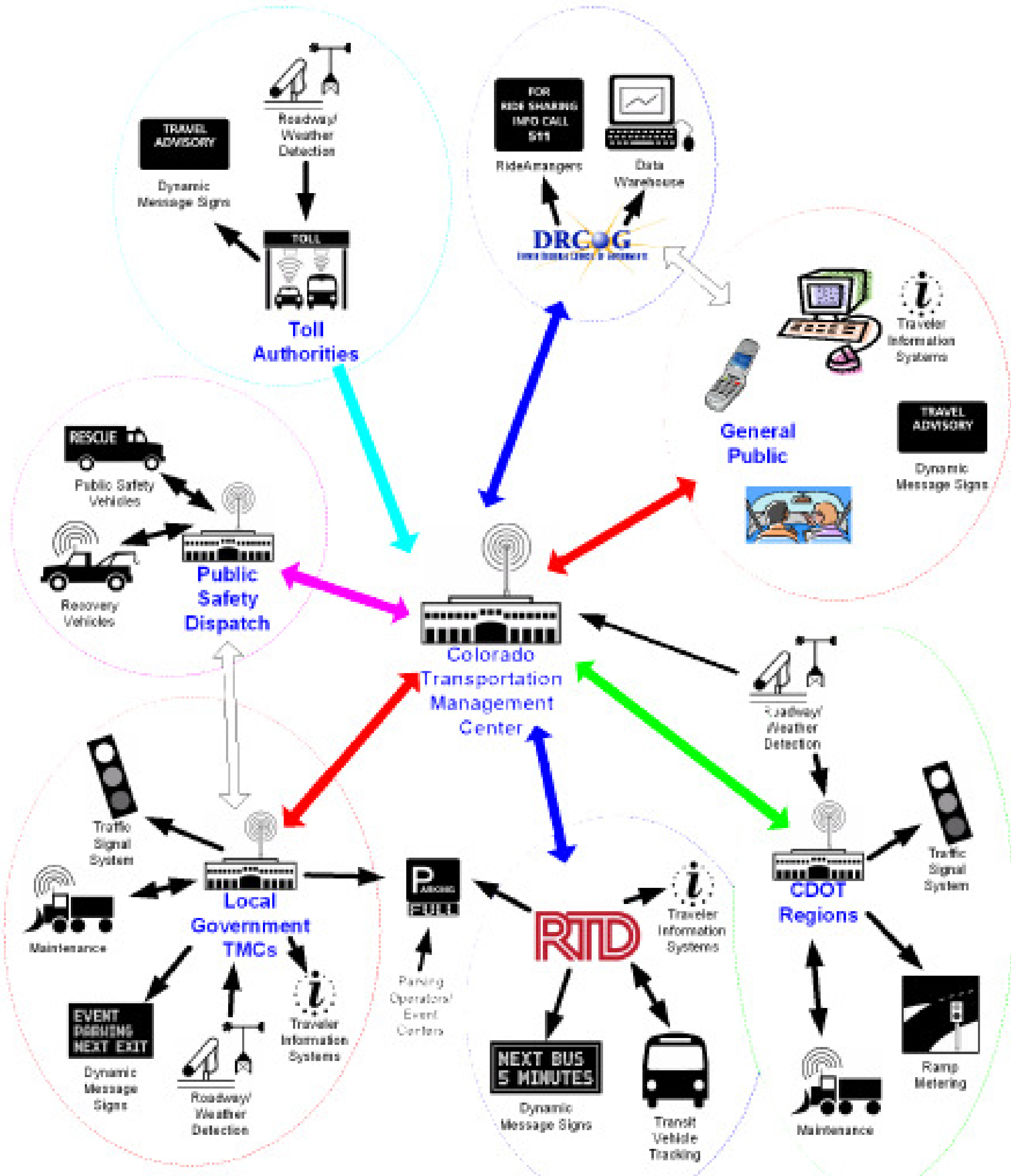

Figure 3-1. Regional Intelligent Transportation System Information Flow Schematic (Source: DRCOG, 2007)

- ***"Multigenerational transit and access"—*** Transit services are developed and provided by the Regional Transportation District (RTD), including light rail (with two stations on the E and F lines at Arapahoe Road (Village Center) and Dry Creek Road[3] and bus service (with routes along Broadway, University, Arapahoe, Quebec, and Smoky Hill). The enhanced TMS can improve transit reliability via TSP, as well as providing parking availability information on the arterial DMS.
- **"*ITS so advanced to be able to remove/repurpose roads"—*** An enhanced traffic-signal control system alone will not provide such a paradigm shift in operations to allow arterials roads in Centennial to be removed or repurposed. However, advances in real-time sensing and control systems and software in the past decade are indeed changing how we consider using vehicles in commercial and private applications. Connected vehicles applications are on the near horizon. Driverless vehicles are already using our roads and present new opportunities and challenges to surface transportation owners and providers. These future vehicle technologies and ITS-related systems will likely significantly impact how the roads are used and how they are operated—in other words, ITS technologies and applications are becoming so advanced that the roads may need to be repurposed in the future.

Additional future considerations for the TMS concept are identified in the *Transportation Master Plan* (City of Centennial, 2013), including the widening of Arapahoe Road between Waco Street and Liverpool Street from two lanes to four lanes initially and six lanes at some later time; and implementing bus rapid transit (BRT) along Arapahoe Road. The widening of Arapahoe Road might offer the opportunity to convert one or more of the future lanes to a "managed lane" for use by transit (i.e., BRT), HOVs, high-occupancy toll (HOT), and/or automated vehicles. Additionally, the enhanced TMS could support BRT operations through TSP. Traveler information on the status of new park-and-ride lots might also be incorporated into the TMS.

3.2 Vision

The purpose of a vision statement is to briefly spell out an aspirational description of what Centennial's enhanced ITS-based TMS will accomplish. Based on the review of current and potential future needs, an understanding of what TSM&O strategies can achieve in the way of benefits, a review of the various references listed in Chapter 1, coupled with the results of a "visioning session" and subsequent workshop with City staff, the following vision statement was crafted:

> *Centennial's transportation management system will be a major component of an overall "Smart City" approach, using advanced operations strategies and innovative technologies to promote high-levels of mobility, reliability, and safety along the City's transportation network, and providing a positive user experience. The system will be developed and operated in an integrated and sustainable manner, providing resilience and flexibility for the future, thereby supporting a vibrant economy and quality of life for the City's growing population.*

3.3 Goals

A goal is a broad statement that describes a desired end state – what an organization wants to accomplish, focusing on outcomes. The establishment of the system goals should stem from the values inherent in the vision statement. The TSM goals should also be compatible and consistent with the

[3] While the stations are not located in Centennial, the arterial network provides access to these stations.

planning factors identified in the federal legislation,[4] the goals identified in the DRCOG *Regional Concept of Transportation Operations* (DRCOG, 2012), and the goal for the region's TSSIP as listed in Table 3-2.

Table 3-2. Relevant Goals from Other Sources

MAP-21 Planning Factors for TSM&O	
• Support economic vitality of the metropolitan area • Increase safety for motorized and non-motorized users • Increase security of the system • Increase people and freight accessibility and mobility • Enhance integration and connectivity of the system, across and between modes	• Protect and enhance the environment, promote energy conservation, and improve quality of life • Emphasize the preservation of the existing transportation system • Promote efficient system management & operation • Emphasize the preservation of the system
Goals from *Regional Concept of Transportation Operations (DRCOG, 2012)*	
• Provide reliable transportation operations for regional travelers. • Provide safe transportation operations for regional travelers and public safety and construction/maintenance personnel. • Provide transportation operations support to non-SOV modes of travel	
TSSIP Goal	
• The region's traffic signals systems will operate in a safe manner making most efficient use of arterial street capacity	

Based on the key words in the vision statement, the relevant goals from other sources, and discussions during stakeholder workshops, several goals for the enhanced Centennial TMS were developed as listed and defined in Table 3-3.

Table 3-3. Goals for the Enhanced Centennial Transportation Management System

- **Mobility—**Help enhance moving people and goods by reducing congestion and recurring delays on the arterial network.
- **Reliability—**Improve the efficiency of the arterial network by reducing non-recurrent delays and increased consistency of travel times from day to day.
- **Safety—**Help significantly reduce crashes, serious injuries, and fatalities, including those of pedestrians and cyclists, on the arterial transportation network.
- **Incident and Event Management—**Minimize the impact of crashes, special events, weather, and other incidents on arterial operations.
- **Environmental—**Help protect and enhance the area environment by reducing emissions and noise from the arterial network and conserving energy.
- **User Experience—**Enhance the experience of all users of the Centennial transportation network by increasing availability and accessibility of information to support better decision-making regarding trips, thereby enhancing users' ability to reach opportunities and activities and generally making their trips better.
- **Integration and Connectivity—**Ensure that the system functions are provided throughout the City in an integrated and multimodal manner and that operations are coordinated with other City agencies—including land use planning and "complete street" initiatives—and with other nearby jurisdictions, transportation and transit entities, and enforcement and emergency service providers.
- **Innovation—**Ensure that all system functions use appropriate and state-of the art technologies and that technologies and operational strategies have flexibility and resiliency in terms of adapting to changing conditions and technology enhancements, while also ensuring that investment decisions for the TMS reflect value.

[4] At the time of developing the CONOPS, this was MAP-21: Moving Ahead for Progress in the 21st Century. A new federal transportation authorization (FAST) was passed by Congress and signed by the President on December 5, 2015. These planning factors have been incorporated into the current version of the National ITS Architecture.

3.4 Objectives

Objectives are specific, measurable statements of performance that will support achieving the goals. The FHWA *Desk Reference and Guidebook* (i.e., Advancing Metropolitan Planning for Operations) emphasizes the importance of each operations objective having "SMART" characteristics as follows:

- **Specific—**The objective provides sufficient specificity (e.g., decrease travel time delay) to guide formulating viable approaches to achieving the objective without dictating the approach.
- **Measurable—**The objective facilitates quantitative evaluation (e.g., by 10 percent), saying how many or how much should be accomplished. Tracking progress against the objective enables an assessment of the effectiveness of an action or set of actions.
- **Agreed—**Planners, operators, designers, and other relevant stakeholder participants come to a consensus on a common objective.
- **Realistic—**The objective can reasonably be accomplished within the limitations of resources and other demands. The objective may require substantial coordination, collaboration, and investment to achieve. Because determining the realism of the objective cannot occur until strategies and costs are defined, the objective may need to be adjusted to be achievable.
- **Time-Bound—**The objective identifies a timeframe within which it will be achieved (e.g., within 5 years).

3.4.1 Outcome-Based Objectives

Operations objectives are preferably described in terms of those system performance outcomes from the perspective of users. Aspects of system performance (i.e., "outcomes") that are important to users include levels of congestion, crashes, travel times and delays, travel time reliability, and access to traveler information. Table 3-4 lists potential outcome-based operations objectives for the enhanced Centennial TMS. These objectives will need to be reviewed by the stakeholders, edited, and then refined and expanded to become "SMART" objectives. For example, the objective "reduce average delay per traveler" as identified in Table 3-4 (as part of the "mobility" goal) would need to be expanded to read "reduce average delay per traveler by X percent by year Y," thereby creating an operations objective that is specific, measurable, and time-bound.

Table 3-4. Potential Outcome-Based Objectives for Centennial Transportation Management System

Goal	Outcome-Oriented Objectives
Mobility	• Reduce average delay per traveler (car and transit trips). • Reduce the daily hours of recurring congestion on major arterials. • Reduce the share of major intersections operating at LOS D or worse. • Reduce travel time index[a] along the arterials.
Reliability (additional info and definitions provided later in this chapter)	• Decrease the average buffer index (for multiple routes). • Reduce the average planning time index (for specific routes). • Increase transit schedule adherence.
Safety	• Reduce the crash rate (per person hours, vehicle miles of travel) by severity (e.g., fatal, serious injury) and roadway type (including work zones). • Reduce the number of crashes involving pedestrians. • Reduce the number of serious injuries and/or fatalities.

Table 3-4. Potential Outcome-Based Objectives for Centennial Transportation Management System

Goal	Outcome-Oriented Objectives
Incident and Event Management	• Reduce mean time of incident duration on arterial facilities (this can be further defined in terms of detection/verification, response, and clearance times). • Reduce the person hours (or vehicle hours) of total delay associated with special events. • Reduce the person hours (or vehicle hours) of total delay associated with significant weather events.
Environment	• Reduce criteria emissions (e.g., nitrogen oxide, carbon monoxide, particulate matter) from vehicles and other transportation-related sources. • Reduce greenhouse gas emissions (e.g., carbon dioxide) from vehicles and other transportation-related sources. • Reduce total fuel consumption per capita for transportation. • Reduce energy consumption of traffic signals. • Reduce energy consumption of street lighting.
User Experience	• Increase customer satisfaction ratings as measured by surveys (this can be segregated by service, such as traveler information, incident management, arterial operations during peak periods, work zone management). • Establish a traveler information website and increase the number of users of the website. • Increase number of users who receive travel information notifications (e.g., e-mail, text message). • Increase number of social media followers (e.g., Twitter, Facebook).
Integration and Connectivity	• Refer to “activity based objectives” in Chapter 8.
Innovation	• Refer to “activity based objectives” in Chapter 8.

[a] Travel time index is defined at the end of this chapter.
LOS level of service

3.4.2 Reliability

Some outcome objectives associated with the “reliability” goal may be new to several stakeholders. The concept of travel time reliability has been receiving significant attention of late, particularly as part of the second Strategic Highway Research Program (SHRP2). The overall goal of the SHRP2 Reliability program is to reduce congestion through incident reduction, management, response, and mitigation, thereby significantly improve travel time reliability for many types of person and freight trips on the nation’s highways. Per SHRP documentation:

> *Travel time reliability refers to how travel time varies over time and the impacts of this variance on highway users. In other words, for repeated travel or vehicles making similar trips, there is an underlying distribution of travel time for a particular type of trip within a specific time period between two points. Individual travelers respond differently to the factors and uncertainties associated with the travel time. So do those involved in freight transportation. For important trips such as a trip to the doctor or a just-in-time freight delivery, the driver (or possibly the freight dispatcher) will build extra time into the trip to ensure arrival within a time window with a high probability, for example 19 out 20 times (=95% of the time).*

The reliability-based objectives included in previous Table 3-4 are defined in Table 3-5, with Figure 3-2 showing these measures and their relationship in the form of a frequency distribution for trip travel times.

Table 3-5. Performance Measures for Reliability

Reliability Measure	Description
Travel time index	This index represents the ratio of travel time during peak period to time required to make the same trip at free-flow speeds. A value of 1.3, for example, indicates that a 20-minute free-flow trip requires 26 minutes during the peak period.
Buffer index	This index represents the extra time (or time cushion) that travelers must add to their average travel time when planning trips to account for any unexpected delay and ensure on-time arrival. This index uses the 95th percentile travel time to represent a near-worst case travel time, and it is computed as the difference between the 95th percentile travel time and average travel time, divided by the average travel time. The buffer index is expressed as a percentage and its value increases as reliability gets worse. An advantage of expressing the reliability (or lack thereof) in this way is that a percent value is distance and time neutral. For example, a buffer index of 40 percent means that, for a 20-minute average travel time, a traveler should budget an additional 8 minutes (20 minutes × 40 percent = 8 minutes) to ensure on-time arrival most times. In this example, the 8 extra minutes is the buffer time.
Planning time index	This index represents how much total time a traveler should allow to ensure on-time arrival, including an adequate buffer time. This index is computed as the 95th percentile travel time divided by the free-flow travel time. For example, a planning time index of 1.60 means that, for a 15-minute trip in light traffic, the total time that should be planned for the trip is 24 minutes (15 minutes × 1.60 = 24 minutes) to ensure on-time arrival 95% of the time. The planning time index differs from the buffer index in that it includes typical delay as well as unexpected delay. Thus, the planning time index compares near-worst case travel time to a travel time in light or free-flow traffic. Moreover, while the buffer index shows the additional travel time that is necessary, the planning time index shows the total travel time that is necessary. The planning time index is especially useful because it can be directly compared to the travel time index (a measure of average congestion) on similar numeric scales.

Note: Both the buffer and planning time indices use a 95th percentile travel time. Other percentiles, such as the 85th, 90th, or even 99th percentile, could be used depending upon the desired level of reliability. For example, a lower percentile may be used in calculating reliability measures for less critical routes or trips.

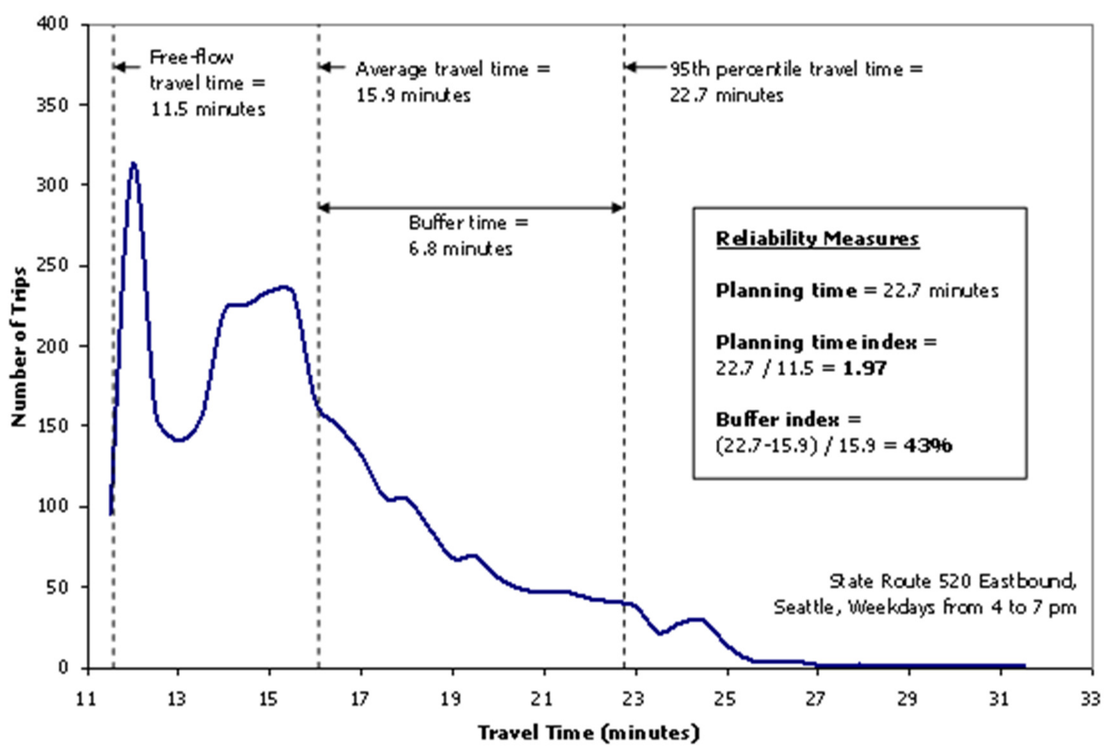

Figure 3-2. Reliability Measures

CHAPTER 4

User-Oriented Operational Description

This chapter identifies the various traffic management stakeholders and discusses how they use and/or interact with the current signal system, and with each other. Table 4-1 summarizes their respective activities. The expected roles of many of these stakeholders with the enhanced TMS are addressed in Chapter 7 (Operational Scenarios).

4.1 Stakeholders

A “stakeholder” many be defined as any person or group with a direct interest (a “stake” as it were) in the operation of the traffic signal system and the enhanced TMS. Many of these stakeholders were involved in the various workshops to develop and review the vision, goals, and objectives for the enhanced TMS.

Of course, the most important stakeholders are the users of the Centennial transportation network, including drivers, pedestrians, cyclists, and transit riders. Their collective mobility and safety, depends on operating the signal system (including appropriate timings and coordination plans) and other associated functions, such as school beacon operation, traveler information, incident management, transit operations, and street lighting. These users and their needs form the basis for the outcome-based objectives as discussed in the previous chapter.

4.2 City of Centennial Public Works Traffic Engineering Services Responsibilities

The management, operation, and maintenance of the traffic signals and signal system (and the recommended TMS) are the responsibility of Traffic Engineering Services of Centennial Public Works. Other responsibilities of Traffic Engineering Services include:

- Managing traffic signs and pavement markings
- Responding to citizen enquiries and complaints regarding problems with signals and other traffic management infrastructure
- Managing the Neighborhood Traffic Management Program, which focuses on improving traffic safety on neighborhood streets by reducing speeding and cut-through traffic, and fostering pedestrian safety.
- Participating in traffic planning studies, including reviewing and commenting on impact studies and plans from developers from the perspective of traffic and operations.

The Community Development Services group[5] within Public Works is responsible for developing capital projects and transportation planning. They are also developing an Infrastructure Design Manual that will include standards for signalized intersections and, in all likelihood, other ITS devices.

[5] There is also a Community Development Department within the City of Centennial. This Department is responsible for ensuring development within the City occurs in an orderly, safe, and attractive manner. Responsibilities include long-range and open-space planning, zoning, and building services.

Other responsibilities of Public Works include design and construction management of capital projects and maintaining and repairing all City streets (including sweeping and pot hole repair), and snow removal.[6]

Centennial has two school districts—Cherry Creek and Littleton. Before the start of each school year, staff from Traffic Engineering Services obtain the school schedules and program the various school beacons accordingly. Centennial also has three fire districts. They have worked with traffic engineering services staff to identify signalized intersections and the associated intersection approaches requiring emergency preemption.

The DRCOG is the designated metropolitan planning organization for Centennial. In this role, DRCOG provides updated signal timings for major corridors in the City once every 3 years. They also review and approve requests for capital grants and funding to install new signal hardware and other ITS-related equipment (e.g., the aforementioned TSSIP).

As previously discussed, the signals along Arapaho Road are operated and managed by multiple agencies and signal systems, including CDOT, Greenwood Village, and Arapahoe County. Additionally, signals that are on City boundaries (e.g., County Line Road) are operated by Lone Tree and Douglas Counties. As previously noted, currently no mechanism is in place for providing coordination across jurisdiction boundaries. These other signal systems use either the Econolite® Centracs (like Centennial) or the TransCore® TransSuite® systems. Moreover, as a general rule, none of the TOC's in these adjacent jurisdictions are regularly staffed, other than CDOT.

In addition to controlling a few signals along Arapahoe Road (in the vicinity of I-25), CDOT also operates and manages I-25 and other freeways in the region network (e.g., ramp metering, incident management, DMS). CDOT also operates the COTRIP.ORG traveler information website and supports video sharing of CCTV images among the various jurisdictions.

Enforcement activities, including responding to incidents and crashes on the arterial network, is provided by the Arapahoe County Sherriff's Department, using patrol vehicles marked as "Centennial Police." The sheriff's office may be notified of a crash by the public (via 911), Centennial Public Works, and CDOT, among others. The sheriff's department includes a Traffic Unit that has been tasked with reducing the number of crashes. This unit may respond to crashes, and also work with the Traffic Engineering Services to develop crash mitigation measures at high crash locations. The Emergency Management Center is also located at the Sherriff's office.

The RTD operates and manages the bus, rail, and light rail transit services in the Denver metropolitan area, including Centennial. Currently, little interaction occurs between the traffic signal system and RTD (e.g., no TSP is in place, nor information regarding parking availability at the light rail stations services by Centennial roads).

Other stakeholders include the various metropolitan districts—special tax districts that provide funding for deploying warranted signals (e.g., as part of new developments). Several major trip generators exist close to Centennial, such as Centennial Airport—one of the busiest general aviation airports in the country.

---

[6] Snow removal operations are contracted to a third party, with the City of Centennial providing the routing information. All the plows are equipped with global positioning system.

Table 4-1. Summary of Centennial Traffic Management Stakeholders

Stakeholder	Signal Operations (Centennial)	Signal Operations (Arapahoe)	Signal Operations (Boundaries)	Signal Pre-emption	School Beacons	Signal Timing	Transportation Planning	Traveler information	Incident Management	Weather Management	Transit Operations
Centennial Public Works – Traffic Engineering Services	X	X		X	X	X			X	X	
Centennial Public Works – Community Development Services							X				
Centennial Public Works – Other									X	X	
Arapahoe County Police									X	X	
Centennial Fire Districts				X							
Centennial School Districts					X						
Arapahoe County		X									
Douglas County			X								
Greenwood Village		X	X								
Lone Tree			X								
CDOT		X					X	X	X	X	
DRCOG						X	X				
RTD							X				X

CDOT Colorado Department of Transportation
DRCOG Denver Regional Council of Governments
RTD Regional Transportation District

4.3 Innovation Considerations

The vision statement for the TMS includes the phrase “innovative technologies,” and many of the concepts provided herein can be described as innovative. There is also an “innovation” TMS goal. In this context, the Centennial Innovation Team and CDOT’s RoadX initiative are two important stakeholders; the TMS concepts identified herein, and their subsequent design and implementation, needs to be coordinated with the activities of these stakeholders.

The Centennial Innovation Team functions as in-house innovation consultants that assess problems, generate innovative responses and develop partnerships to fix these problems—in essence, accelerating and embedding innovation into local government. The Innovation Team is funded through a 3-year, $1.5 million grant from Bloomberg Philanthropies. Centennial was one of 12 U.S. and two international cities to be selected to participate in the expansion of Bloomberg Philanthropies' Innovation Teams program. Many concepts proposed by the Innovation Team focus on the transportation network and its operation, including operational coordination along Arapahoe Road.

RoadX is CDOT's bold commitment to its customers to be a national leader in using innovative technology to improve the transportation system. The RoadX visions is to transform Colorado's transportation system into one of the safest and most reliable in the nation by harnessing emerging technology. This will be accomplished by partnering with public and industry partners to make Colorado one of the most technologically advanced transportation systems in the nation, and a leader in safety and reliability.

The Centennial Innovation Team has been working closely with the RoadX staff at CDOT to develop a project along I-25 northbound from Ridge Gate Parkway to University, which will incorporate the Australian concept of "managed motorways" (i.e., data collection sensors, variable speed limits and message signs, and ramp metering).[7] This project may very well have implications for developing and operating the proposed Centennial TSM in terms of traveler information (DMS) and signal timing.

[7] Known as Active Traffic Management in the United States.

CHAPTER 5

System Overview and Concept

This chapter provides an overview of the Centennial TMS and the operational enhancements to the current systems, including modes of operation, new capabilities, and interfaces to other systems and organizations. How the recommended TMS helps to achieve the operational objectives and needs are also discussed. Conformity with the regional ITS architecture is also addressed. The Centennial TMS will incorporate both a geographic expansion and functional enhancements of the City's traffic signal control system plus additional ITS systems as discussed below. Additional information on the proposed changes and/or additions to field components and to the central hardware and software, as well as a plan for TOC operations, is provided in the next chapter.

5.1 Manage Operations

The TMS will monitor and control—in real time—all the current and future signalized intersections in the City. The TMS will have the ability to upload / modify / download local controller parameters for each and every signalized intersection (a function the current signal system already provides). The TMS will provide the following operational modes for implementing timing plans:

- Time of day/day of week selection of plans, including as a minimum AM peak, PM peak, shoulder periods, off peak, and night (refer to Figure 5-1).

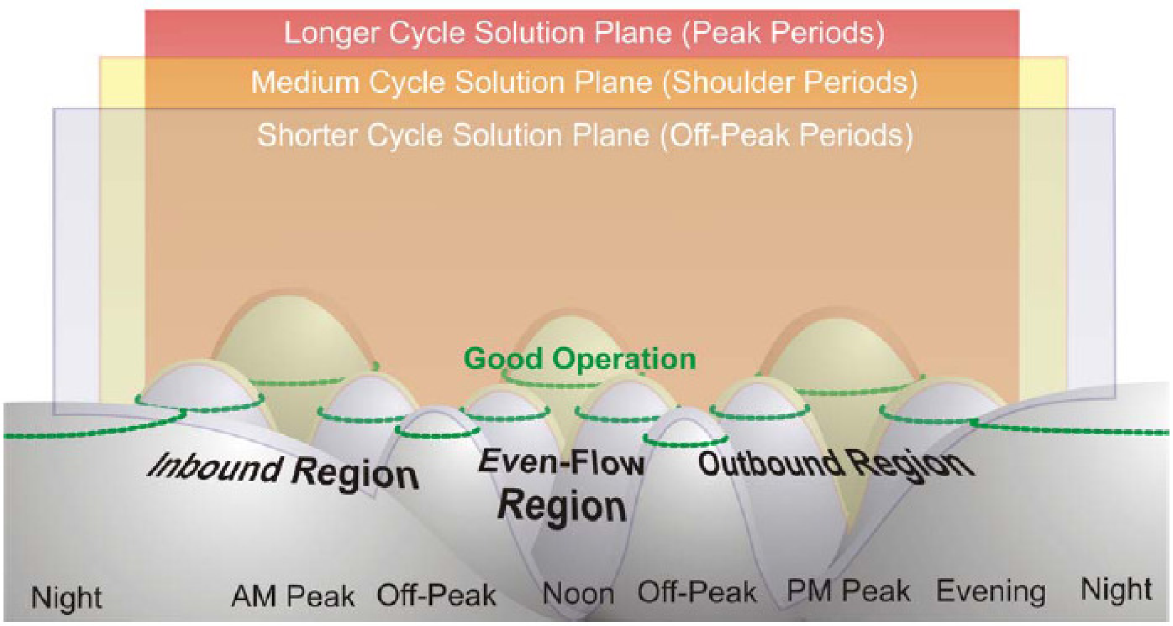

Figure 5-1. Timing Plan Considerations

- Traffic responsive selection where the system selects from a library of timing plans, including those developed for special scenarios such as inclement weather, incident conditions, special events, diversions from the freeways, based on current traffic flow conditions and/or weather/roadway conditions (e.g., snow, ice, reduced visibility).
- Manual selection of timing plans by TOC operators and other qualified staff, including adjusting timing parameters as may be required.

A related activity the City will perform, in cooperation with DRCOG, will be to regularly evaluate the performance of the timing plans stored in the system, adjusting them and/or developing new ones as required to optimize traffic flow for all recurring and special conditions. The TMS will provide tools to aid this effort, such as an interface to traffic optimization software (e.g., Synchro), time-space diagrams, and split-monitor displays.

Signal coordination along the entire length of Arapahoe Road and across other jurisdiction boundaries will be accomplished via "center-to-center" (C2C) links with the surrounding jurisdictions' TMSs, plus formal agreements between all the involved entities (including Centennial) addressing continuity of timing plans between jurisdictions, common-time reference, and operating protocols during atypical events (e.g., major incidents, diversions, inclement weather). This may include the ability—and with permission from the other agencies—for one agency to access the other TMSs and select and/or modify timing plans during certain operational conditions and scenarios. The Centennial TMS will also provide additional operational features, including the following:

- Control and monitoring of all school beacons and beacons, including the ability to modify and override the schedule resident at the beacon location as may be required due to unforeseen conditions (e.g., later start, early dismissal, closures)
- Control and monitoring of DMS installed along City arterials to provide real time information to drivers for making trip decisions en-route, including information on traffic conditions on the major freeways and ramps in the vicinity of Centennial.
- Coordinated incident management activities[8] between Centennial, the Arapahoe County Sheriff, Colorado State Police, and other emergency service providers. This will involve sharing real-time video and congestion information with the County Sheriff such they can immediately determine the appropriate response, dispatch the proper resources, and let the responders know the best route to the incident scene.

5.2 Monitor Roadway Conditions

Additional monitoring and surveillance components—including detection technologies (for measuring volumes and speeds), CCTV cameras, road weather information systems (RWIS) and Bluetooth readers (for measuring travel times) will be installed along all major arterials in Centennial (see textbox to right). These real time data and information will be used by the TMS and Centennial staff in support of several functions:

Major Arterials

- Arapahoe Road
- Dry Creek
- Smoky Hill
- Havana
- Jordan
- Himalaya

- Automated selection of timing plans in the traffic responsive mode
- Automated selection of timing plans in response to extreme weather conditions
- Manual selection of timing plans or modifying timing parameters in response to extreme weather conditions or unusual traffic flows
- Identification and verification of incidents or other unusual conditions on the arterial network and monitoring of the incident response activities and the impact on traffic flows (e.g., modifying signal timing)

[8] Traffic incident management is defined as "systematic, planned, and coordinated use of human, institutional, electrical, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders. These resources are also used to increase the operating efficiency, safety, and mobility of the surface transportation network by systematically reducing the time to detect and verify an incident occurrence; implementing the appropriate response; and safely clearing the incident, while managing the affected flow until full capacity is restored..

- Traveler information on arterial DMS. Additionally, the information is transmitted to CDOT for use in the regional traveler information system (e.g., COTRIP.ORG).
- Performance measurement

With respect to the latter, performance measurement is key to ensuring that TMS goals and outcome objectives (as discussed in Chapter 3) are met. In essence, if you don't measure results, you can't tell success from failure; if you can't see success, you can't reward it; and if you can't see failure, you can't correct it. Additionally, performance data may be used to identify trends for operators, planners, decision-makers, and the public to determine where trouble spots exist and to inform investment decisions.

The Centennial TMS will automatically collect and archive data and use this information to automatically calculate measures of effectiveness associated with the performance measures (which, in turn, are based on the outcome objectives) and display results in tabular and graphical formats. The operator will be able to define the time periods of the analyses.

These geographic and functional expansions—coupled with the additional information as discussed below—will help achieve many of the goals, including mobility, safety, reliability, incident and event management, environmental, and user experience.

5.3 Manage and Maintain Transportation Management System

With the additional features and functions provided by the TMS, it will be of great value for the TOC to be staffed during peak traffic flow periods to ensure that the TMS and field components (e.g., signals, beacons, DMS) are working properly, to review CCTV images to identify any congestion or incidents requiring additional attention, to manually change timing plans and parameters as conditions may dictate, to identify any malfunctions and contact the appropriate maintenance contractors, and to coordinate with adjacent jurisdictions.

The TMS will also continuously monitor itself and all field equipment for faults or malfunctions that may affect the system's ability to properly control traffic flow (a function the current system already provides). This information will be displayed on the operator workstations in the TOC and will also be transmitted to traffic engineering staff—with three levels of priority—via text or email. This, coupled with traffic engineering staff having remote access to the TMS, will enable traffic engineering staff to diagnose the problem and contact the appropriate contract maintenance forces as appropriate when the TOC is not staffed.

Managing the TMS will be further enhanced by having up-to-date documentation (e.g., operations, users, and maintenance manuals) on all aspects of the system, including central software and hardware, communications network, and field devices. The operator's documentation may also include flow charts identifying the sequence of actions and contacts for various operational scenarios. The TMS documentation will be indexed and referenced so that any required information can be quickly found. An asset management system will allow traffic engineering staff to keep all information regarding system components up to date.

5.4 Employ Enhanced Communications

The existing fiber and wireless communications networks will be expanded to accommodate the additional traffic controllers and school beacons controlled and monitored by the TMS (i.e., communication links to all current and future signalized intersection and beacons in the City). Additionally, the communications network will accommodate the data and video information associated with the additional surveillance and monitoring devices. The expanded and enhanced communications network for the TMS will be part of the city-wide fiber network as defined in the recent City of Centennial Fiber Master Plan. The communications network will also provide C2C connectivity—for transmitting data on traffic flow conditions, signal status, video—between the Centennial TOC and the following:

- CDOT and DRCOG, in support of regional traveler information and ICM activities
- Arapahoe County Sherriff's Office (remote workstations and video displays and control), in support of incident and emergency management
- Adjacent jurisdictions (e.g., Greenwood Village, Arapahoe County) and CDOT, for signal coordination along Arapahoe Road and for providing signal coordination across jurisdiction boundaries
- Public Works/snow removal contractor (remote workstation), for real-time information regarding weather and road conditions in support of snow removal.

As discussed in the next chapter, C2C connectivity should be a by-product of interagency and regional coordination and collaboration, including developing memoranda of understanding and related agreements for multiagency and regional operations and incident management, which the C2C communications will support from a technical perspective. This will also help achieve the goal of integration and connectivity.

5.5 Consider Future Enhancements

Other enhancements to the Centennial TMS should be considered as listed below. These enhancements will likely be implemented (if at all) beyond the 5-year time frame of this CONOPS and the associated Implementation Plan. Nevertheless, these assumptions may change over the 5-year period, resulting potentially in an earlier implementation. These longer-term TMS enhancements include the following:

- **Traffic adaptive mode of operation** for intersections that may experience widely variable and less predictable traffic conditions; with adaptive mode timing parameters are automatically developed and implemented by the system in real time based on traffic flow conditions.
- **Direct control over all the traffic signals along between along Arapahoe Road between E-470 to the west and Broadway to the east**. The current concept calls for maintaining coordination across jurisdiction boundaries via C2C connections between their respective systems and associated agreements. However, as traffic management becomes more proactive (e.g., automated selection of timing plans based on traffic flows, weather and roadway conditions, major incidents, diversion), direct control by a single jurisdiction's system (most likely Centennial) may prove beneficial.
- **TSP for RTD buses operating along Centennial-controlled arterials, including any future BRT operations.** The TSP will be "conditional;" that is, TSP will not be activated at a signal unless the approaching bus is behind schedule. This will require RTD to have a global positioning system-based system for buses that includes real-time schedule adherence information, wireless communications between the buses and each signal where TSP is implemented, and additional hardware in the controller cabinets to process the priority requests.
- **Traveler information from RTD regarding the status of park-and-ride lots near Centennia**l; information that can be posted on the arterial DMS. This will require a C2C communications link between the Centennial TMS and RTD.
- **A Centennial "Traveler Information" website**, with possibly text and twitter feeds, focusing on traffic flow and roadway conditions on Centennial roadways, plus operations of the relevant bus and light rail routes.

- **Connected Vehicles (CV).** The CV program initiatives at USDOT and within the automotive industry are rapidly shifting from research program to real-world application; and this on-going process will undoubtedly have an impact on the future operation and ITS deployments within Centennial and the entire Denver metropolitan region. The vehicle to infrastructure (V2I) aspect of connected vehicles is clearly the most important to consider for the future of the Centennial TMS. The traffic management and traveler information concepts all use sensor technologies embedded in, above, and/or around the road to determine real-time traffic flows and obtain other information (e.g., weather and roadway conditions). The CONOPS and its 5-year time frame includes such detectorization; however CV will eventually represent a major technical advancement that could lead to wholesale replacement of such fixed detection subsystems by simply transmitting a basic message including identity, location, speed, and trajectory to roadside readers, other vehicles, and signal controllers. Eventual conversion of the fleet, where essentially 100 percent of vehicles communicate basic safety messages, would provide a whole new approach to a more refined and highly automated traffic management capability. From a safety perspective, the USDOT US DOT estimates a reduction of unimpaired driver accidents by as much as 80% through collision warning, weather information, situational awareness, driver advisors, and congestion reduction (Figure 5-2.) Additionally, Arapahoe Road might be considered as an arterial test bed for such V2I and related innovative applications, including automated vehicles.

Figure 5-2. Example of Connected Vehicles at a Signalized Intersection

5.6 Context within the National Intelligent Transportation System Architecture

The National ITS Architecture, maintained by the USDOT, is a comprehensive, common and mature framework for developing and integrating transportation systems at the state and regional levels. The National ITS Architecture, therefore, serves as a guide, available to ITS professionals for developing integrated transportation systems. FHWA Rule 940, which became effective in 2001, implemented Section 5206(e) of the Transportation Equity Act for the 21st Century (TEA-21), requires ITS projects that are funded, in whole or in part, with the highway trust fund to conform to the National ITS Architecture and standards. The rule states that "conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture." Assuming federal funds will be used for some of the enhancements to the Centennial traffic signal system as summarized here, implementing TMS will need to be "Rule 940 Compliant."

In the strictest sense, the proposed TMS does not conform to the current regional ITS architecture, for the simple reason that the architecture—last updated and published in 2007—indicates (quite literally) that the City of Centennial has "No ITS, No signal system, No other ITS functions, and No Architecture Subsystems." Moreover, in the regional architecture's "Market Package" Plans—showing "existing," "planned" (for short-term future deployment), and "considered" (for longer term) market packages by jurisdiction and agency—the City of Centennial is not even listed.

Obviously, the Denver Regional ITS Architecture is in great need of updating, not only for Centennial, but presumably for other jurisdictions and to reflect the latest version of the National ITS Architecture (Version 7.1, that was released in April 2015). Moreover, per Rule 940, "If the final design of the ITS project is inconsistent with the regional ITS architecture, then the regional ITS architecture shall be updated to reflect the changes."

One of the changes in Version 7 is that the term "market package" has been replaced by "service package," where a service package is a grouping of different subsystems and communication flows needed to deliver a desired transportation service. Service packages can work separately, or in combination, to address the real-world transportation needs and desires identified through traditional planning activities. When the Denver Regional ITS Architecture is updated, it should include the service packages identified in Table 5-1 for the recommended Centennial TMS.

Table 5-1. National Intelligent Transportation System Architecture Service Packages Applicable to the Centennial Transportation Management System Concept

Network Surveillance (ATMS01)—This service package includes traffic detectors, other surveillance equipment, the supporting field equipment, and fixed-point to fixed-point communications to transmit the collected data back to the Traffic Management Subsystem.
Traffic Probe Surveillance (ATMS02)—This service package provides an alternative approach for surveillance of the roadway network.
Traffic Signal Control (ATMS03)—This service package provides the central control and monitoring equipment, communication links, and the signal control equipment that support traffic control at signalized intersections.
Traffic Information Dissemination (ATMS06)—This service package provides driver information using roadway equipment such as DMS.
Regional Traffic Management (ATMS07)—This service package provides for the sharing of traffic information and control among traffic management centers to support regional traffic management strategies. Regional traffic management strategies that are supported include interjurisdictional, real-time coordinated traffic signal control systems and coordination between freeway operations and traffic signal control within a corridor.
Traffic Incident Management System (ATMS08)—This service package manages both unexpected incidents and planned events so that the impact to the transportation network and traveler safety is minimized. The service package includes

Table 5-1. National Intelligent Transportation System Architecture Service Packages Applicable to the Centennial Transportation Management System Concept

incident detection capabilities through roadside surveillance devices (e.g., CCTV) and through regional coordination with other traffic management, maintenance and construction management and emergency management centers as well as rail operations and event promoters.

Roadside Lighting System Control (ATMS12)—This service package includes systems that manage electrical lighting systems by monitoring operational conditions and using the lighting controls to vary the amount of light provided along the roadside. These systems allow a center to control lights based on traffic conditions, time-of-day, and the occurrence of incidents.

Dynamic Roadway Warning (ATMS24)—This service package includes systems that dynamically warn drivers approaching hazards on a roadway. Such hazards include roadway weather conditions, road surface conditions, traffic conditions including queues, obstacles or animals in the roadway and any other transient event that can be sensed.

Mixed Use Warning Systems (ATMS26)—This service package supports the sensing and warning systems used to interact with pedestrians, bicyclists, and other vehicles that operate on the main vehicle roadways, or on pathways which intersect the main vehicle roadways.

Maintenance and Construction Vehicle and Equipment Tracking (MC01)—This service package will track the location of maintenance and construction vehicles and other equipment to ascertain the progress of their activities. These activities can include ensuring the correct roads are being plowed and work activity is being performed at the correct locations.

Road Weather Data Collection (MC03)—This service package collects current road and weather conditions using data collected from environmental sensors deployed on and about the roadway (or guideway in the case of transit-related rail systems).

Weather Information Processing and Distribution (MC04) —This service package processes and distributes the environmental information collected from the Road Weather Data Collection service package. This service package uses the environmental data to detect environmental hazards such as icy road conditions, high winds, dense fog, so system operators and decision support systems can make decision on corrective actions to take.

Winter Maintenance (MC06) —This service package supports winter road maintenance including snow plow operations, roadway treatments (e.g., salt spraying and other anti-icing material applications), and other snow and ice control activities. This package monitors environmental conditions and weather forecasts and uses the information to schedule winter maintenance activities, determine the appropriate snow and ice control response, and track and manage response operations.

Roadway Maintenance and Construction (MC07)—This service package supports numerous services for scheduled and unscheduled maintenance and construction on a roadway system or right-of-way. Maintenance services would include landscape maintenance, hazard removal (roadway debris, dead animals), routine maintenance activities (roadway cleaning, grass cutting), and repair and maintenance of both ITS and non-ITS equipment on the roadway (e.g., signs, traffic controllers, traffic detectors, DMS, traffic signals, CCTV).

Work Zone Management (MC08)—This service package manages work zones, controlling traffic in areas of the roadway where maintenance, construction, and utility work activities are underway. Traffic conditions are monitored using CCTV cameras and controlled using DMS.

Transit Signal Priority (APTS09)—This service package determines the need for transit priority on routes and at certain intersections and requests transit vehicle priority at these locations.

Broadcast Traveler Information (ATIS01)—This service package collects traffic conditions, advisories, general public transportation, toll and parking information, incident information, roadway maintenance and construction information, air quality and weather information, and broadcasts the information to travelers using technologies such as FM subcarrier, satellite radio, cellular data broadcasts, and Internet web casts.

Transportation Operations Data Sharing (ATIS06) —This service package makes real-time transportation operations data available to transportation system operators. The Information Service Provider collects, processes, and stores current information on traffic and travel conditions and other information about the current state of the transportation network and makes this information available to transportation system operators, facilitating the exchange of qualified, real-time information between agencies.

Emergency Routing (EM02)—This service package supports automated vehicle location and dynamic routing of emergency vehicles. Traffic information, road conditions, and suggested routing information are provided to enhance emergency vehicle routing.

Wide-Area Alert (EM06)—This service package uses ITS driver and traveler information systems to alert the public in emergency situations such as child abductions, severe weather events, civil emergencies, and other situations that pose a threat to life and property.

Table 5-1. National Intelligent Transportation System Architecture Service Packages Applicable to the Centennial Transportation Management System Concept

ITS Data Mart (AD1)—This service package provides a focused archive that houses data collected and owned by a single agency, district, private sector provider, research institution, or other organization. This focused archive typically includes data covering a single transportation mode and one jurisdiction that is collected from an operational data store and archived for future use.
ITS Data Warehouse (AD2)—This service package includes all the data collection and management capabilities provided by the ITS Data Mart, and adds the functionality and interface definitions that allow collection of data from multiple agencies and data sources spanning across modal and jurisdictional boundaries. It performs the additional transformations and provides the additional meta data management features that are necessary so that all this data can be managed in a single repository with consistent formats.

CCTV	closed-circuit television
DMS	dynamic message signs
ITS	Intelligent Transportation System

CHAPTER 6

Operational and Support Environment

This chapter identifies and describes the changes to existing system components plus any additional system elements – in the field and at central (e.g., hardware and software at the TOC) – and the necessary internal and external system interfaces to achieve the overall TMS operational concept. This chapter also includes a discussion of the staffing and related operational and maintenance needs associated with the TMS concept. Based on discussions with Centennial Public Works staff, it is assumed that the basis for the TMS will be the current Centracs signal system and the Econolite® controllers, with modifications and enhancements as required to achieve the operational concept and overall vision.

6.1 Field Components

6.1.1 Communications Network

The *Transportation System Communications Master Plan* (City of Centennial, 2010) recommends a 20-year hybrid communications system with fiber optics for the system backbone and full motion video connections, and data radios for other field connections. The actual implementation of the communications network has not followed the plan, per se, but rather has been based on opportunities, such as the installation of conduit and fiber as roadway improvement projects have been constructed. These opportunities, coupled with DRCOG grants has allowed the City to create a fiber-optic network that includes communications along significant stretches of Arapahoe Road, Dry Creek Road, Buckley Road, Smoky Hill Road, Easter Avenue, Peoria Street, and Jordan Road. However, due to the segmental and opportunistic approach for creating and expanding this communications network – including connections to traffic signal controllers – there is not yet complete physical or logical redundancy built into the system as identified in the 2010 plan.

As previously noted, Centennial recently developed a comprehensive Fiber Master Plan for expanding Centennial's foundational fiber network to support current and future municipal and community needs and to accommodate "smart city" technologies and approaches. The Fiber Master Plan addresses the communication needs for the traffic signal system and other ITS devices that would become part of the integrated TMS.

- The *Transportation System Communications Master Plan* should be updated to reflect the actual implementations of the communications network to date and the city-wide fiber master plan. The focus of the updated ITS communications plan should be on connecting all the remaining signals to the system before the fiber network is completed and in place (e.g., via wireless), and implementing the necessary C2C links. These C2C links should include connections between the TMS and the following:Public Works (remote workstation for information on traffic conditions, weather and road conditions, and in support of snow removal)
- CDOT for coordination along Arapahoe Road, regional traveler information, video sharing, and any future ICM activities
- Greenwood Village, Lone Tree, Arapahoe County, and Douglas County for coordination along Arapahoe Road and other cross-jurisdiction arterial coordination
- Arapahoe County Sherriff's office (remote workstation and video displays and control) in support of coordinated incident and emergency management

- DRCOG and RTD in support of data sharing and possible TSP in the future

Additionally, communications in support of remote access to the signal system by traffic engineering services staff (via their laptops or a tablet) should also be provided.

6.1.2 Controllers and Cabinets

All the existing Econolite® controllers are compatible with the Centracs signal system. Nevertheless, is it recommended that these ASC controllers eventually be replaced with Econolite "Cobalt" Advanced Transportation Controllers and that smart conflict monitors, thereby providing additional functionality and monitoring capabilities plus the ability to incorporate innovative concepts in the future. Key signalized intersections should also have uninterruptable power supplies (UPS) installed in the cabinets to provide signal control even during short power outages, with the UPS (both existing and new ones) connected to the TMS for remote status monitoring at the TOC and alerts to traffic engineering staff.

A future consideration for traffic signal controllers and cabinets is the implementation of TSP for the RTD bus routes (i.e., along Broadway, University, Arapahoe, Quebec, and Smoky Hill) and any future BRT operations. The architecture for any TSP will need to be developed jointly with RTD. It will likely require additional hardware in the controller cabinets to receive a request for priority from an approaching bus, as well as logic to determine whether priority can be given (e.g., has a minimum number of signal cycles elapsed since the last priority was granted) and interface with the controller to implement the required sequence (e.g., extend main street green, early main street green for queue jump).

6.1.3 School Beacons

Additional hardware will likely be required in the school beacon cabinets and at the TOC, coupled with communications between the beacons and the TOC, to allow the normal school beacon schedule to be input from the TOC, and also overridden from the TOC whenever there is a late start, early dismissal, or unscheduled school closings. Moreover, the additional hardware should allow the TOC to monitor when the beacons are on and off to verify proper operation.

6.1.4 System Detectors

System detectors will be installed along the major arterials – nominally mid-block, such that queues from downstream traffic signals typically do not reach the detector locations, with a set of detectors covering each lane and each direction. The system detectors should be located at a minimum between every major intersection,[9] and upstream and downstream from major trip generators. As a minimum, the system detectors should measure volumes, occupancies, and speeds. It is envisioned that the detectors will be connected to the nearest traffic signal controller for data processing and transmission back to the TOC and the Centracs system. As previously noted, these system detector data would be used in real-time for traffic responsive operation and traveler information (DMS and transmitted to CDOT for use in the regional traveler information systems), and processed and stored for use in planning, timing plan development, and performance management.

[9] For example, along western segment of Arapahoe Road, this would entail a set of system detectors between Broadway, University, Colorado, Holly, and Quebec.

6.1.5 Road Weather Information Systems

Additional RWIS stations, measuring atmospheric conditions (e.g., temperature, humidity, barometric pressure, visibility, wind speed and direction) and road conditions (e.g., dry, water, ice/snow, grip, temperature) should be installed along the major signalized arterials and other significant routes where the Centennial Public Works is responsible for snow removal (i.e., Priority 1 roadways, which include major arterial streets, streets with four or more travel lanes and streets that provide access for emergency responses; and Priority 2 roadways, which include minor arterial and major collector streets that connect the major arterial streets to residential streets, including school zones, major office areas and larger retail establishments.) These data will be used to select appropriate inclement weather timing plans, for traveler information (e.g., posting warnings on DMS) and for use by Public Works and their contractor as part of their snow removal planning and operations (Figure 6-1).

Figure 6-1. Centennial Snow Plow

6.1.6 Closed-Circuit Television Cameras

As previously noted, CCTV cameras with pan-tilt-zoom capabilities are currently being installed along Arapahoe Road, Dry Creek Road, and Smoky Hill Road (refer to previous Figure 2-9), and connected into the regional Nicevision regional video sharing network. Additional cameras should be installed to fill in any gaps in coverage to allow Centennial staff – and emergency service providers such as the Arapahoe County Sheriff via C2C connections -- to view all the major arterials in the City.

6.1.7 Dynamic Message Signs

Arterial DMS – nominally mounted on mast arms such as shown in Figure 6-2 – should be installed along the major arterials in advance of major decision points, such as the ramps to I-25, and other locations to be determined, thereby providing drivers information on traffic flow conditions along the roadways (including the Interstates and the ramps) and potential downstream roadway hazards (weather, major crash, closure). DMS may also be installed along potential diversion routes.

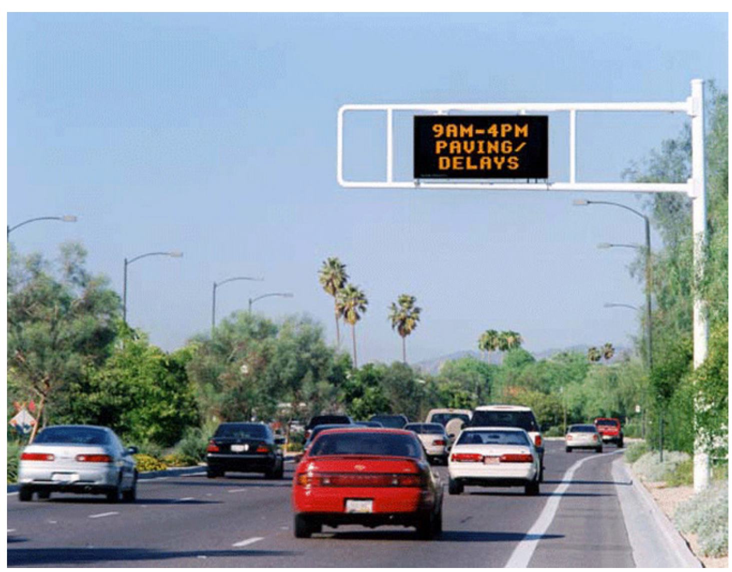

Figure 6-2. Example of Arterial Dynamic Message Signs

6.2 Central Components

The current Centracs signal system – coupled with the Econolite® ASC controllers – is already capable of providing many of the operational concepts and functions required for the TMS, including:

- Coordinated operations of all existing and future signalized intersections in Centennial, utilizing multiple timing plans
- Various methods for selecting timing plans for an individual intersection, a section/sub-area of intersections, or on a system-wide basis, including manual, schedule (i.e., daily, weekly, annually, holidays) and traffic responsive[10].
- Provide remote upload/download of controller timing and coordination parameters, including the ability to modify all these parameters from the TOC workstation and via remote access to the system
- Real-time monitoring of signal system and intersection operations, including current signal displays, operational mode (coordinated operation, free, programmed flash, pre-emption, TSP service), and error detection and reporting (e.g., conflict flash, loss of power, loss of communications, timing out of synch with selected timing plan, potential detector failures)
- Data processing from detectors, including summary information displayed on the workstation maps
- Systems analysis and engineering tools such as time-space diagrams, split-monitor displays, and various system and operations reports.

Implementing the TMS concept will require a significant amount of database work for the signal system – for example: to integrate the remaining signals into the system including the map display, to accommodate and process data from the system detectors, to input additional timing plans into the system, to develop the "signatures" (volume plus scaled occupancy) for each timing plan associated with traffic responsive operations, and to set up the automated alarm capability (i.e., identify the levels of priority for each type of potential alarm, and identify traffic engineering staff to whom the alarms will be sent, when, and by which method such as text and email).

To achieve the TMS concept, functional enhancements and additions to Centracs will be required, including the following as a minimum:

- **C2C Operations**: The key C2C functionality is to maintain coordinated signal operation along Arapahoe Road and across other jurisdiction boundaries. As a minimum, the linkages should incorporate a common time reference and ensure that all systems are using consistent timing plans (e.g., common cycle lengths, appropriate offsets) according to a pre-arranged and approved time-of-day/day-of-week schedule, provide status information on all signals (e.g., off line, under system control, failure), and identify the available timing plans. Centracs has an optional "server-to-server" module[11] that allows agencies to share real-time signal status and detector data. This module also allows one agency to remotely command signal patterns and perform other control level operations on other connected systems – a potentially useful feature for implementing consistent timing along Arapahoe Road and across jurisdiction boundaries during non-scheduled events such as inclement weather.

---

[10] Centracs uses data provided by system detectors for traffic responsive selection of timing plans, utilizing a "V+kO" (volume plus scaled occupancy) algorithm developed by the US Department of Transportation for traffic-responsive operations.

[11] The module only works with other Centracs systems; but development of similar functionality with other vendor's systems is possible.

- **DMS Control**: The system should provide integrated control of the arterial DMS, including developing and storing a message library, entering parameters for the automated selection and display of messages (from the library) based on real-time data from system detectors and RWIS, and development and display of "on-the-fly" messages by an operator in response to unusual conditions not covered in the DMS library. Monitoring of DMS (e.g., sign status, communications, message displayed) should also be provided. Centracs does offers an optional DMS module that supports NTCIP 1203 objects associated with DMS devices and is capable of polling sign status as well as commanding messages to DMS devices. This module also allows icons for DMS devices to be displayed on the system map with the ability to launch a sign status display capable of viewing and modifying the current message on a sign. This module should be investigated for possible inclusion in the TMS.

As previously noted herein, CCTV control will be provided as part of the Nicevision regional video sharing system, with all Centennial CCTV cameras to be integrated into this system, which will provide PTZ control, as well as allow the video displays to be managed and selected at the TOC. Centracs does offer an optional CCTV module, but it is doubtful if this will be required. This approach will result in CCTV control and management being a system separate from Centracs—although that is not considered any sort of problem from an operational perspective, particularly in light of the regional information sharing provided by Nicevision. Additionally, with the additional cameras and video information, additional wall monitors and/or a video display management system may be necessary in the TOC.

Other TMS features and functions will also be provided as noted below; although whether these will be integrated into the Centracs signal system, or whether some of these will function as a separate system in the TOC (with potential links to Centracs for data exchange and display on the system workstations), still needs to be determined:

- **School Beacons:** The TMS concept includes central control of the school beacons—providing the ability to override the regular schedule as special and unforeseen conditions may dictate—as well as the ability to monitor operation of the beacons from the TOC. This likely will be a separate and independent system from Centracs.

- **RWIS Data Integration**: The Centennial TMS concept includes the integration of RWIS data into the signal system to support the automated selection of timing plans developed specifically for various types and severities of inclement and hazardous weather – a form of "weather responsive timing plans" – and also possibly the automated display of relevant DMS messages (e.g., "ICY CONDITIONS AHEAD", "LOW VISIBILITY, DRIVE WITH CAUTON." The information should also be displayed on the system map for use by Centennial Public Works in support of snow removal operations. Centracs does not offer this RWIS feature as an optional module. If integrating RWIS data directly into Centracs Is not feasible, then providing some of these functions via a C2C interface to a separate RWIS system might be possible. At a minimum, the RWIS data can be reviewed by a TOC operator to manually select and activate the most appropriate timing plan and/or develop and display DMS messages.

- **Performance Management:** The TMS should aggregate, process, and analyze data from system detectors and from other systems (e.g., link travel times from CDOT as provided by INRIX) to automatically develop performance metrics such that the City can monitor the extent to which the outcome objectives (refer to previous Table 3-4) are being achieved. This feature may be fully integrated into the Centracs (with additional software); or perhaps an offline system may be provided that uses data from the Centracs (and from other sources) to automatically develop the performance metrics that are aligned with the outcome objectives.

- **System Documentation and Asset Management:** The system documentation should be brought up to date – including operations and maintenance manuals on all system-related hardware and software, communications network as-builts and diagrams, controller cabinet wiring diagrams, timing plans and associated parameters (as examples) – and regularly updated. Moreover, this information should be digitized and stored in a document management system so that it can be easily accessed by system operators, maintenance staff, and managers and administrators. Additionally, an asset management system should be implemented to help keep track of all the system components as the TMS expands. Centracs offers an optional Maintenance Management System, providing the following features:

– Definition of classes of assets and inventory
– Tracking of individual assets and their histories of preventive maintenance, location changes, failure and repair histories and depreciation.
– Definition of preventive maintenance activities and schedules for individual locations by location and asset type
– Manual documentation of trouble calls
– Mobile web interface for field personnel and technicians

6.3 Traffic Operations Center Operations Plan

The additional central components discussed in the previous section will likely require an expansion of the existing TOC to accommodate the additional servers, workstations, and video displays.

Managing roadway operations to achieve the vision, goals, and objectives requires sufficient operations staff equipped with the capability to monitor operations, modify systems controls, adjust traveler information and coordinate with other stakeholders to respond to incidents and other non-recurring congestion due to work zones, special events, and weather. To take full advantage of the additional features and functions to be provided by the TMS, it is recommended that the TOC be staffed with one operator during the AM and PM peak periods and as may be required during other periods of nonrecurring congestion (e.g., weather, crash resulting in major diversions to the Centennial arterial network). The TOC operators' activities and responsibilities will include:

- Monitor the system and field devices (i.e., controllers, school beacons, DMS) for proper operation.
- Monitor traffic flows, congestion, and field device operation via the map display and CCTV images (using "camera tours" whereby video images of key locations are routinely and automatically displayed on the video wall).
- Identify any system malfunctions and contact the appropriate maintenance contractors, also entering the information in the TMS asset management system
- Identify and log any incidents (from the monitoring activities) and contact Arapahoe County Sherriff and others in accordance with established incident management procedures. Provide additional information and coordination as requested.
- Manually implement special timing plans as conditions (weather, incidents, diversions) may require
- Manually change timing parameters for scenarios where an appropriate special timing plan is not available
- Implement DMS messages (from the DMS library or develop a new message) for congestion, weather, incident, and other abnormal conditions
- Override school beacon schedules as may be required for late starts, early dismissals, and unplanned closures
- Coordinate operations with Public Works during snow removal operations

- Coordinate with CDOT and adjacent jurisdictions to provide synchronized signal operations along Arapahoe Road and across jurisdiction boundaries under all traffic flow, incident, and weather conditions, and to provide consistent regional traveler information via DMS

When not in the TOC and operating and managing the TMS, these staff will support other activities within Traffic Engineering Services, including analyzing system and other data in terms of performance metrics and identifying trouble spots, working with DRCOG and other stakeholders to update timing plans and developing new plans for special conditions, review and update parameters for traffic responsive selection of timing plans, review and update the DMS libraries, review and update operational procedures and associated decision flowcharts, assist with the review of impact studies for new developments and the review of design plans for new signals, assist with responding to citizen complaints and inquiries regarding TMS operations, assist with analyzing and reviewing performance by maintenance contractors, and assist with the on-going coordination and collaboration with CDOT, adjacent jurisdictions, and the Arapahoe County Sheriff and other emergency service providers.

With respect to the last item, interagency and regional coordination will include developing memoranda of understanding and related agreements (which the C2C communications will support from a technical perspective.) These agreements should address institutional responsibilities and issues, operational considerations (e.g., coordinated timing plans, policies and procedures for changing and updating plans, operations during special conditions such as weather and major diversions, consistent traveler information), and technical issues (e.g., C2C standards); see textbox to the right

Key Elements for Interagency Agreements

- Participants and Operational Coverage
- Purpose, Need, and Authority
- Roles and Responsibilities
- Adoption, Duration, Amendment, and Termination
- Funding and Financial Arrangements
- Appendices (e.g., management plans or other technical supporting documents).

An NCHRP Report[12] summarizes several characteristics of effective agreements:

- An agreement should be pursued in a spirit of mutual compromise. A willingness to compromise and to treat others as equal partners helps establish an environment that is conducive to cooperation. Each participant should take the time to gain an understanding of the issues that affect the other partners and to be cognizant of those issues when generating alternatives. The potential benefits to each party through participating in and supporting the process should be made as clear as possible.
- It is vital to proactively confront the tough corridor management issues through direct involvement of the affected parties. It is important to keep all parties to the agreement appraised of substantive developments throughout the process to ensure a smooth transition from the corridor management plan to the agreement.
- Establish a joint committee or multiparty amendment process for the administration of a corridor management plan. Establishing an administrative structure through the agreement, such as a committee to administer a corridor management plan or a provision for multiparty approval of amendments, can help formalize the decision-making process, improve intergovernmental coordination and communication, and reduce the potential for amendments that conflict with corridor management objectives.

The development of such a Regional Signal Operations Group (RSOG) to address interagency signal operations and traveler information is recommended as part of the TOC Operations Plan. It may prove beneficial to start with a small group focusing solely on coordinated operations along Arapahoe Road,

[12] From Reference 12: NCHRP Synthesis 337 (Cooperative Agreements for Corridor Management). Additional information is provided in Technical Memorandum 3.4.

and then expand the group to address other routes and potential diversions from the freeway and ramps. The activities of the RSOG will be to identify the capabilities of each agencies systems, develop approaches and standards for C2C connections between the systems, and to develop and agree on multiagency approaches for various operational scenarios, including those described in the next chapter. These approaches and the respective responsibilities should also be documented in memoranda of understanding.

Similarly, it is recommended that an Incident Management Task Force, comprised of representatives from the City, enforcement entities, emergency service providers, and DRCOG, be formed to address incident management activities and inter-agency issues. In addition to general relationship building, activities of the Task Force may include after-action debriefs and lessons learned, incident management training (e.g., the National Incident Management System, or NIMS[13]), and developing diversion route plans and operational scenarios.

[13]The National Incident Management System is a unified national framework for incident management, providing a consistent nationwide approach for Federal, state, local, and tribal governments; the private sector; and non-governmental organizations to work effectively and efficiently together to prepare for, respond to, and recover from domestic incidents, regardless of cause, size, or complexity

CHAPTER 7

Operational Scenarios

This chapter contains high-level descriptions of likely operational scenarios associated with the Centennial TMS, including conditions that trigger the scenario, underlying assumptions, TOC operators' responsibilities and actions, and coordination between stakeholders. The examples are not meant to be all inclusive; but they do provide an understanding of TMS capabilities, processes and operations given certain events within and around the City. The following scenarios are presented:

- Off peak
- Peak periods
- Severe weather
- Work zones
- Major crashes/diversions
- Minor incidents
- Failure conditions

An underlying assumption for all the scenarios is that operational procedures have been developed for these and other scenarios, including flow charts (e.g., "if – then" statements and decision trees, including operator actions, timing plans and DMS messages to implement, contacts to be made, etc.) for use by TOC operators to guide their activities. Another assumption is that the RSOG has been established to address interagency signal operations and traveler information, and this group has developed and documented policies and procedures for operations along Arapahoe Road[14]. Each operational scenario and associated procedures should also be compatible with established emergency management plans. Additionally, all DMS messages will conform to approved language and messaging conventions.

7.1 Off Peak

This scenario addresses typical off-peak and shoulder times of the day, including weekends. In general, congestion is not an issue with minimal saturation flow or loaded cycles (i.e., a vehicle has to wait through at least one green phase before proceeding through the intersection). Table 7-1 summarizes this operational scenario.

7.2 Peak Periods

This scenario addresses operations during recurring peak periods – both AM (6 to 9) and PM (3 to 7) – when significant congestion and saturated flows typically occur. Table 7-2 summarizes this operational scenario.

[14] These interagency procedures will also be included in the TOC operational procedures and flowcharts.

Table 7-1. Off-Peak Transportation Management System Operations

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	No staff typically in TOC during off-peak periods	Traffic Engineering Services staff will be able to access the system remotely via their laptops.
Timing Plan Selection	TOD/DOW schedule	When enabled, traffic responsive will automatically select shoulder plans if traffic flows warrant an earlier or later implementation of these plans.
DMS Messages	Dark or blank out	As an alternative, “public relations” and safety-oriented messages (e.g., DON’T TEXT AND DRIVE) may be posted.
School Beacons	Per normal school schedules	
Arapahoe Road Coordination	Automated via C2C links, individual system schedules, and off-peak timing plans as approved by the RSOG	Coordination across jurisdiction boundaries may not always be required during off-peak periods, particularly at night.
Stakeholders/Contacts	Minimal, except for RSOG planning	

C2C center-to-center
DMS dynamic message signs
RSOG Regional Signal Operations Group
TOD/DOW time of day/day of week

Table 7-2. Peak-Period Transportation Management System Operations

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	One operator at a minimum	Duties and responsibilities of the TOC operator are identified in Chapter 6 as part of the TOC Operations Plan.
Timing Plan Selection	Peak-period plans on TOD/DOW schedule	Traffic responsive will be enabled to automatically select peak-period plans if traffic flows warrant an earlier or later implementation. Manual override by operator, including changing timings at individual intersections, in response to saturated conditions or a minor incident, is also possible.
DMS Messages	Automated selection from DMS library based on traffic flows, TOD/DOW schedule, or manual	With manual operation, the TOC operator may select other messages from the library or develop and display a completely new message as traffic flow conditions warrant (e.g., minor incident).
School Beacons	Per normal school schedules	
Arapahoe Road Coordination	Automated via C2C links, individual system schedules, and peak-period timing plans as developed and approved by the RSOG	If traffic flow conditions warrant earlier implementation of peak-period plans, TOC operator contacts other agencies (CDOT, Greenwood Village, Arapahoe County, and Lone Tree) to inform them of this change. Depending on the final C2C functionality and inter-agency agreement, the TOC operator may access other jurisdictions’ signal systems and implement the peak period plan in advance of the schedule, notifying RSOG partners of the change.
Stakeholders/Contacts	In addition to adjacent agencies for signal operations (i.e., RSOG), TOC operator will contact Arapahoe County Sheriff regarding any incidents (and vice versa) and contact Public Works regarding any debris in the roadway impacting traffic flow.	

C2C center-to-center
CDOT Colorado Department of Transportation
DMS dynamic message signs
RSOG Regional Signal Operations Group
TOC Transportation Operations Center
TOD/DOW time of day/day of week

7.3 Work Zones

This scenario addresses operations during long-term work zones (e.g., roadway reconstruction or widening). It is assumed that Traffic Engineering Services staff have been involved in the work zone planning, including the maintenance and protection of traffic work zone activities. Table 7-3 summarizes this operational scenario.

Table 7-3. Long-Term Work Zone Transportation Management System Operations

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	No change in normal schedule (i.e., one operator during peak periods; although on-roadway work activities or lane closures are typically not permitted during peak periods)	If work zone activities and lane configurations change from those originally planned, the contractor should contact the City at least 24 hours prior to the proposed change so that Public Works can coordinate with Traffic Engineering Services staff.
Timing Plan Selection	Plans developed specifically for work zone operations, selected on TOD/DOW schedule	For a major unplanned change in the work zone plans, and upon notification by Public Works, the operators may manually select another timing plan and/or modify timing parameters, either remotely or at the TOC.
DMS Messages	Automated selection from DMS library (including DMS messages developed specifically for the work zone) based TOD/DOW schedule	For a major unplanned change in the work zone plans, and upon notification by Public Works, the TOC operators may manually select another DMS message from the library or create a new one.
School Beacons	Per normal school schedules	
Arapahoe Road Coordination	For work-zone impacts, multiple agencies along Arapahoe Road, special timing plans, and schedules for work zone activities should be developed and approved by the RSOG; these plans would be selected via C2C links and the individual system TOD/DOW schedules	For a major unplanned change in the work zone plans, and upon notification by the jurisdiction/agency managing the construction project, the operators in other impacted jurisdictions may manually select another approved plan more suitable for the changes. Depending on final C2C functionality and interagency agreement, the lead agency may access other jurisdictions' signal systems and implement the other approved plan, notifying the RSOG partners of the change.
Stakeholders/Contacts	Community Development Services and Public Works for work zone planning, as well as RSOG if the work zone impacts Arapahoe Road. Public Works and possibly Arapahoe County Sheriff for changes in the work zone plans.	

C2C	center-to-center
CDOT	Colorado Department of Transportation
DMS	dynamic message signs
RSOG	Regional Signal Operations Group
TOC	Transportation Operations Center
TOD/DOW	time of day/day of week

7.4 Severe Weather

This scenario addresses operations during severe weather, such as a snow storm with reduced visibility and snow removal operations. It is assumed that this severe weather scenario and its intensity and timing had been forecasted at least 1 or 2 days in advance. One or more special timing plans are also assumed to have been developed for such wintry conditions. Table 7-4 summarizes this operational scenario.

Table 7-4. Severe Weather Transportation Management System Operations

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	One operator at a minimum	Depending on severity, an additional staff member may be required to assist. Staff will arrive at TOC prior to the storm.
Timing Plan Selection	Combination of automated based on data from RWIS (if cost-effective and feasible for TMS) and manual by operator based on review of data from RWIS and review of real-time video images	Timing plans for severe winter conditions should be developed to accommodate significantly slower vehicle speeds. If icing and/or visibility is a potential problem, then increasing clearance intervals at major intersections for duration of the icing/low visibility conditions, providing vehicles additional time to clear the intersection before displaying green to a conflicting approach, might be beneficial.
DMS Messages	Combination of automated selection from DMS library based on data from RWIS (if cost-effective and feasible for TMS), and manual by the operator based on review of data from RWIS and review of real-time video images	Manual selection of messages from the library or developing new messages (not in the library) by the TOC operator as may be required, depending on the weather and road conditions.
School Beacons	Operators may override the normal schedules to accommodate late starts, early dismissals, and/or closings	Decision to change schedules or close schools is the responsibility of school districts. Operator will regularly communicate with the school districts to determine if schedule changes are needed and parameters for these changes.
Arapahoe Road Coordination	Minimal coordination across boundaries, unless all involved agencies have developed similar and consistent timing plans for severe weather conditions	During severe weather, coordination across jurisdiction boundaries is not a major issue relative to other operational concerns. Operators should communicate with centers of other agencies, assuming these other centers are staffed during the storm.
Stakeholders/Contacts	In addition to communications with the school districts and surrounding agencies, ongoing communications will likely be necessary between TOC and Public Works, Arapahoe County Sheriff, and Emergency Operations Center.	

DMS dynamic message signs
RWIS road weather information system
TMS Transportation Management System
TOC Transportation Operations Center

7.5 Multiple Lanes Major Incidents and Closures

This scenario addresses operations during a major incident that closes several lanes (or a complete closure) of a major facility, resulting in traffic diverting to various segments of the Centennial arterial network. The example for this scenario would be a closure of multiple lanes for 1 hour or more in one or both directions of I-25 somewhere between the East County Line Road and the Arapahoe Road interchanges, resulting in traffic diverting from I-25 onto South Yosemite Road via Arapahoe Road and County Line Road. An underlying assumption with this example is that the RSOG has developed contingency plans and operations protocols as part of a broader ICM strategy, and that the Incident Management Task Force has also identified response and diversion scenario plans. Table 7-5 summarizes this operational scenario.

Table 7-5. Major Incident and Diversion Transportation Management System Operations (Preplanned)

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	Depends on time of incident (i.e., the TOC is staffed during peak periods). For a major incident resulting in significant diversions during off-peak periods, an operator would likely staff the TOC once notified and stay throughout the event.	CDOT or Colorado State Police will notify Centennial Traffic Engineering Services staff of the major incident on I-25.
Timing Plan Selection	Manual selection of special timing plans previously developed for this scenario, accommodating the increased traffic on the arterial roadways.	Based on a review of real-time data from system detectors and video images from along affected routes, operator may adjust timing plans to better accommodate diverted traffic.
DMS Messages	Manual selection of DMS messages previously developed for this scenario from the DMS library.	TOC operator may develop new messages, depending on traffic flow conditions. Messages would be posted most DMS throughout the Centennial arterial network, warning traffic of problems on I-25 and the resulting congestion on surrounding streets.
School Beacons	Implement per normal school schedules.	
Arapahoe Road Coordination	Manual implementation of the appropriate timing plan as developed and approved by the RSOG for such a scenario.	Under the ICM concept and the associated interagency agreements, CDOT may be authorized to directly implement the scenario timing plans on behalf of all agencies via the C2C links between the systems.
Stakeholders/Contacts	Ongoing communications among Centennial TOC, CDOT, Arapahoe County Sheriff, and State Police are required.	

C2C center-to-center
CDOT Colorado Department of Transportation
DMS dynamic message signs
I-25 Interstate 25
ICM Integrated Corridor Management
RSOG Regional Signal Operations Group
TOC Transportation Operations Center

7.6 Other Minor Incidents

The previous scenario addressed a major incident involving significant lane closings and diversions, but one where contingency plans and multiagency approaches have already been developed and approved. Undoubtedly, many incidents will not have such a regional impact. None the less, a crash or unplanned work zone on a major arterial street will likely close a lane and, therefore, increase congestion, and possibly diversions to other arterials. In these circumstances, TMS operations will require more “on-the-fly” decision making in coordination with other stakeholders. Table 7-6 summarizes this operational scenario.

Table 7-6. Other Minor Incidents Transportation Management System Operations

Operations Parameters	Primary Approach	Other Considerations
TOC Staffing	Depends on time of incident (i.e., the TOC is staffed during peak periods, when such incidents will cause the greatest congestion and impacts). For a minor incident (in terms of duration and lane blockage) that occurs during off peak periods, the TOC may not require staffing unless assistance is requested by the Arapahoe County Sheriff.	During peak periods, a crash may be identified by the TOC operator as a result of continuous review of real-time traffic flow data and video images, in which case the operator should contact the Arapahoe County Sheriff. During off-peak periods, Arapahoe County Sheriff will contact Traffic Engineering Services staff if traffic management assistance is required.
Timing Plan Selection	During peak periods, the operator may need to adjust the peak-period plan to accommodate reduced capacity resulting from the incident.	Timing plan selection would be based on a review of real-time data from system detectors and video images from along the affected routes.
DMS Messages	During peak periods (and if requested by Arapahoe County Sheriff during off-peak periods), new messages may need to be developed and posted on the DMS.	
School Beacons	Approach is per normal school schedules.	
Arapahoe Road Coordination	If the incident/unplanned work zone occurs on Arapahoe Road, and changes to the peak period plans are required, then the TOC operator contacts other agencies to inform them of the changes being made.	Depending on the final C2C functionality and interagency agreement, TOC operator may access other jurisdictions' signal systems and implement changes to peak-period plans to accommodate impacted traffic flows and better provide coordination across jurisdiction boundaries and notify RSOG partners of the change.
Stakeholders/Contacts	Arapahoe County Sheriff, Public Works, and RSOG agencies coordination as may be required.	

C2C center-to-center
DMS dynamic message signs
RSOG Regional Signal Operations Group
TOC Transportation Operations Center

7.7 System and Component Failures

The TMS will continuously monitor itself and all field equipment for faults or malfunctions that may affect the system's ability to properly manage traffic flow. Replacing the ASC-2 controllers with ASC-3 units (and advanced conflict monitoring units), and connecting the UPS to the system will also provide additional details regarding potential faults. This information will be displayed on the workstations in the TOC such that, when the TOC is staffed, the operator can contact the appropriate maintenance staff. When the TOC is not staffed, alerts will automatically be transmitted to traffic engineering staff – with three levels of priority – via text or email. Staff can then remotely access the TMS, diagnose the problem and contact the appropriate contract maintenance forces as appropriate.

7.7.1 Power

Installing UPS in the controller cabinets at key intersections will allow these critical intersections to function during power outages.[15] The TOC currently has back up power capability.

[15] The UPS should be linked to the system such that staff are alerted when an intersections has shifted from primary to UPS power.

7.7.2 Communications

The City of Centennial Fiber Master Plan and its subsequent implementation (including providing redundancy and fiber “rings” will help keep most, if not all, TMS communications operational in the event of a single failure in the network. Even with the loss of communications to some of the signals, coordinated operation will remain for some period of time due to the distributed architecture of the signal system.

The architecture of the Centracs signal system (on which the TMS is based) is “distributed” such that signal timing plans and TOD/DOW schedules are also stored in the local controllers, and the controllers have time clocks that are regularly synched by the system. Thus, in the event of a loss of if communications from the TOC are lost, then the local intersection controllers will revert to these timing plans and schedules and use the local clock, thereby maintaining a high degree of signal coordination in a manner that should be transparent to the drivers, except during unusual events such as severe weather and major diversions. Traffic responsive selection or manual input of timing parameters from the TOC will no longer be possible under this scenario, nor will real-time access to traffic flow data be available from the system detectors. Additionally, under this failure scenario, coordination along Arapahoe Road will be limited unless all the controllers have the same and coordinated timing plans and TOD/DOW schedules stored in local controller, and the local controllers from different jurisdictions are using the same time reference – an important consideration when developing the C2C links between the systems. Local time clocks tend to drift apart over a few days without resynching from the signal system; thus, coordinating under a long-term communications failure will degrade.

7.7.3 Dynamic Message Signs

It is recommended that the arterial DMS be designed that in the event of a communications failure or a power failure, the signs go blank. No message is better than an erroneous message when it comes to traveler information.

CHAPTER 8

Summary of Impacts

This final chapter discusses potential needs and constraints on developing the recommended TMS and associated concepts has described herein. Potential performance measures for the TMS are also discussed.

8.1 Impacts and Potential Constraints

The TMS concepts have been developed with the various goals in mind (as discussed in Chapter 3; see textbox to right). The enhanced transportation management activities described herein will help the City reach the various outcome objectives associated with these goals. That said, there are some potential constraints and unknowns at this time with respect to making these TMS concepts a reality, including the following:

Goals for the Centennial Transportation Management System

- Mobility
- Reliability
- Safety
- Incident and Event Management
- Environmental
- User Experience
- Integration and Connectivity

- **Funding—**The TMS concepts involve additional hardware and software, and will require capital funds to design, purchase, implement, integrate, and test these components. Grants should be available for many of the capital costs; for example, CMAQ funds have been used in Centennial for upgrading controllers, implementing reliable communications, expanding the signal system to include additional signals, and for extending the traffic monitoring infrastructure (with either a 100 or 80 percent federal share, depending on the specific activity.[16] Moreover, additional annual funding will be required for maintenance of the additional TMS components and for the TOC operators. These estimated costs are addressed in the Implementation Plan.
- **Technology—**Some TMS concepts involve innovative strategies that may stretch the state-of-the-practice. One example in this regard is the proposed C2C connections and interfaces between the Econolite® Centracs signal system (as used by Centennial, Greenwood Village and others) and the TransCore® TranSuite® system (as used by CDOT) in support of coordinated operations along Arapahoe Road.[17] Another concept is presented herein is the automated selection of weather-related timing plans and DMS messages by the TMS based on real-time data from the RWIS stations; this is not a feature in the current Centracs (nor is there an optional module). Additionally, the capability to transmit the RWIS data directly to an external system is also a potential issue.[18]
- **Communications Network—**This is another technology concern—and perhaps the most important one. A reliable, robust, and secure communications network—between the TOC and all the field components, and the C2C connections—is key to the overall success of the TMS. As previously noted, once the city-wide fiber master plan is implemented, such a reliable and secure communications network is expected to be in place.

---

16 Per DRCOG documentation, CMAQ funds may also be used to facilitate operations across multiple agencies.

17 Based on recent discussions with Econolite® and TransCore®, this should not be a problem or entail significant costs.

18 The alternative, as previously noted, is for the TOC operators to review the RWIS data and manually select and implement the appropriate weather-related timing plans and DMS messages.

- **Institutional Coordination—**Any technology issues associated with C2C connectivity are nothing compared to the potential institutional issues, and the associated coordination and collaboration between the various agencies that manage traffic within or very near to Centennial's borders. The creation of the Regional Signal Operations Group—perhaps starting just with those agencies involved in the operation of Arapahoe Road—should start immediately. This group that will need to address and resolve a numerous in support of coordinated operations along Arapahoe Road under any and all scenarios. The TOC Operations Plan in Chapter 6 and the scenarios in Chapter 7 discuss many of these issues.

8.2 Potential Benefits

The investment in deploying the ITS Master Plan as defined in this CONOPS can be expected to provide numerous benefits, including:

- Reductions in stops and delays – ITS technologies and operational strategies promote smoother traffic flows and reduce recurring congestion in support of the Mobility goal. For example, enhanced signal operations in other cities, including frequent retiming of the signals, has shown to reduce delays by 5 to 40%, with a reduction in stops of 10% to 40%[19].
- Faster incident response and clearance times – Information sharing and on-going coordination with emergency service providers allows the appropriate incident responders to immediately know about an incident and to determine the appropriate response in terms of the numbers and types of vehicles and personnel to be dispatched to the scene. Sharing of video also allows emergency service providers and transportation operations staff to monitor the clearance operations. Traveler information devices can also be used to direct traffic away from the incident scene.
- Reduced crashes – Smoother traffic flow and a decreased number of stops provided by enhanced signal operations also reduces the crash frequency in support of the Safety goal. RWIS systems, and the associated traveler information and weather-responsive traffic signal control, can decrease rear-end crashes by 20 to 40% during severe weather conditions[20]. Additionally, faster incident response and clearance times can reduce the occurrence of secondary incidents (i.e., crashes occurring in the congestion caused by an incident).
- Improved travel time reliability – Improved and smarter signal operations, coupled with reduced crashes, keeps traffic flowing which gives commuters a more reliable commute.
- Fuel savings and reduction in air pollution – The decreased congestion and the reduced number of stops brought about by ITS implementations also reduce fuel consumption and greenhouse gas emissions, in support of the Environmental goal, compared with normal driving conditions

8.3 Performance Measures

Performance measures are indicators that provide the basis for evaluating the operation of the TMS (i.e., determining the extent to which benefits are being realized) and identifying the location and severity of congestion and other problems. Performance measures provide the public and decision-makers with information on the observed impacts, provide feedback on system performance, provide a solid foundation for any future decisions regarding potential expansion of the system, and provide a

[19] http://www.itsbenefits.its.dot.gov/

[20] http://www.itsbenefits.its.dot.gov/

reproducible evaluation framework. Increased customer expectation and public sector accountability have helped to focus attention on performance measurement as one of the essential tools of transportation management; and this is particularly true for any traffic management scheme. In essence – if you don't measure results, you can't tell success from failure; if you can't see success, you can't reward it; and if you can't see failure, you can't correct it.

Performance measures used for the TMS are inextricably tied to outcome-based objectives, such as those identified in previous Table 3-4. One step of this process is for the TMS stakeholders to review, edit, and then refine these objectives such that they become "SMART."[21] For example, the objective "*reduce average delay per traveler*" (as identified in previous Table 3-4 as part of the "mobility" goal) would need to be expanded to read "*reduce average delay per traveler by X percent by year Y*" – with the values of X and Y being determined by the stakeholders. With such SMART objectives, identifying associated performance measures is obvious because they are identified in the objective statements. Table 8-1 summarizes potential performance measures that have been derived from the potential outcome-based objectives. In finalizing the list of objectives and the corresponding performance measures, the following attributes of good performance measures should be remembered:

- **Goals and objectives—**Performance measures should be identified to reflect the goals and objectives for the management system, including validation of the objectives.
- **Limited number of measures—**All other things being equal, fewer rather than more measures is better. Too much information, too many kinds of information, or information presented at too fine a level can overwhelm decision makers and the public.
- **Ease of collection—**The data required for performance measures should be easy to collect and analyze, preferably directly and automatically from the TMSs.
- **Data needs—**At the same time, performance measures should not be solely defined by what data are readily available. Data needs and the methods for analyzing the data should be determined by what is needed to create or ''populate'' the desired measures.
- **Sensitivity—**Performance measurement must be designed in such a way that change is measured at the same order-of-magnitude as will likely result from the implemented actions.
- **Facilitation of improvement—**The ultimate purpose of performance measures must clearly be to improve the operation of the transportation network. Performance measures must therefore provide the ability to diagnose problems and to assess outcomes that reveal actual operational results.
- **Simple and understandable—**Within the constraints of required precision, accuracy, and facilitating improvement, performance measures should prove simple in application with consistent definitions and interpretations

Under the proposed operational concept, many of the activities associated with the performance measurement "process"— including data collection and archiving, data integration and fusion, analyses and development of metrics, and performance measurement reports—will be performed automatically by the TMS.

[21] Specific, Measurable, Agreed, Realistic, Time-Bound

Table 8-1. Potential Performance Measures for Centennial Transportation Management System

- Average delay per traveler (car and transit trips)
- Daily hours of recurring congestion on major arterials
- Number of major intersections operating at LOS D or worse
- Travel time index
- Total person hours of delay by time period (e.g., peak, off-peak) caused by all transient (i.e., nonrecurrent) events (e.g., traffic incidents, special events, and work zones)
- Average buffer index (for multiple routes)
- Average planning time index (for specific routes)
- Crash rate (i.e., per person hours, vehicle miles of travel) by severity (e.g., fatal, serious injury) and roadway type (including work zones)
- Number of crashes involving pedestrians
- Number of serious injuries and/or fatalities
- Mean time of incident duration on arterial facilities
- Person hours (or vehicle hours) of total delay associated with special events/weather
- Criteria emissions (e.g., nitrogen oxide, carbon monoxide, particulate matter) from vehicles and other transportation-related sources
- Greenhouse gas emissions (e.g., carbon dioxide)) from vehicles and other transportation-related sources
- Total fuel consumption per capita for transportation
- Energy consumption of traffic signals
- Energy consumption of street lighting
- Customer satisfaction ratings as measured by surveys

LOS level of service

Considering and adopting **activity-based objectives** that relate directly to processes and activities that need to be undertaken to achieve the TMS operational concept is also important. For example, the need to integrate the rest of the signals into the system, provide remote access to the system for traffic engineering staff, and improve documentation are such “activities” that are needed to make the proposed TMS a reality and, accordingly, help achieve the various outcome-based objectives. Potential activity-based objectives for the Centennial TMS are listed in Table 8-2.

Table 8-2. Potential Activity-Based Objectives

- Update the Transportation System Communications Master Plan (City of Centennial, 2010).
- Establish communications and connectivity to all major corridors, stakeholders, and ITS devices in the City (i.e., internal connectivity in support of data sharing and operational coordination); and do so in a “redundant” fashion to ensure continuous operations during an emergency or system failure (in accordance with the updated Transportation System Communications Master Plan (City of Centennial, 2010).
- Integrate all signals into the TMS.
- Provide coordinated operation of Arapahoe Road the entire length of Centennial.
- Formalize the signal coordination, communications, and information sharing with other agencies, including the creation of a coalition, and developing procedures and identifying responsibilities in support of Integrated Corridor Management strategies (e.g., major incident on I-25 resulting in traffic diverting to arterial streets).
- Expand coverage of real-time traffic flow detection (e.g., volumes, speeds, and congestion levels) on major arterials in support of signal coordination, traveler information, and performance management.
- Expand coverage of real-time weather and roadway condition surveillance along major arterials in support of automated selection of timing plans, traveler information, snow removal operations, and performance management.
- Automate the traffic data collection and processing activities (e.g., ADT, congestion and reliability indices, travel times, other performance measures).
- Develop and integrate into the signal system additional timing plans for recurring conditions as well as special timing plans for use during incidents, special events, inclement weather conditions, work zones and diversions from the freeways.
- Shift the operational approach from reactive to more proactive, including automated selection of the expanded number of timing plans based on real-time traffic flow information and/or weather and roadway surface condition data.
- Provide remote access capabilities to the signal system for traffic engineering staff.
- Configure and activate the automated alert features of Centracs such that traffic engineering staff can be notified of any system issues.
- Improve/update the documentation of the existing (and future) systems, including what data are available, where housed, and how to access.
- Implement an associated Asset Management System for all ITS and TMS-related devices and software.
- Implement CCTV cameras on all major arterials to provide full visual coverage in support of incident and event management.
- Provide DMS along major arterials plus other means (e.g., web, social media, texts) for distributing traveler information regarding traffic conditions in Centennial and beyond.
- Establish communications and central control of all school beacons
- Adopt accepted standards for all system components.
- Establish standard practices and approaches for expanding, enhancing and monitoring performance of the TMS.
- Implement common hardware and software components throughout the City, thereby increasing the efficiency of maintenance and expansion.
- Implement TSP along selected corridors in support of enhanced bus operations.
- Improve operations via HOV incentives.
- Implement “smart street lighting” technologies and strategies to reduce power consumption and improve visibility.
- Develop an ITS test bed for researching and experimenting with newer technologies.

ADT	average daily traffic
CCTV	closed-circuit television
DMS	dynamic message signs
HOV	high-occupancy vehicle
I-25	Interstate 25
ITS	Intelligent Transportation System
TMS	Transportation Management System
TSP	traffic signal priority