ATKINS

Concept of Operations

I-70 East Tolled Express Lanes

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CDOT I-70 East

VERSION CONTROL

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ACRONYMS

ACRONYM	DESCRIPTION
AASHTO	American Association of State Highway and Transportation Officials
AET	All Electronic Tolling
ALPR	Automatic License Plate Recognition
ATM	Active Traffic Management
ATMS	Advanced Traffic Management System
ATR	Automatic Traffic Recorder
AVI	Automatic Vehicle Identification
AVC	Automatic Vehicle Classification
BOS	Back Office System
CCTV	Closed-Circuit Television
CDOT	Colorado Department of Transportation
CSC	Customer Service Center
CSP	Colorado State Patrol
CTMC	Colorado Transportation Management Center
CTMS	Colorado Transportation Management System
DMV	Department of Motor Vehicles
DRCOG	Denver Regional Council of Governments
DWL	Double White Line Crossing
E-470	E-470 Public Highway Authority
ELOM	Express Lanes Operations Manager
ETC	Electronic Toll Collection
ETTM	Electronic Tolling and Traffic Management
FHWA	Federal Highway Administration
Free Flow	Traffic moving freely without significant oscillation in average speed
GP lanes	General-Purpose Lanes
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
HOV 2+	Two-or-more Person Carpool
HOV 3+	Three-or-more Person Carpool
HPTE	High Performance Transportation Enterprise
ICD	Interface Control Document
ILEV	Inherently Low Emissions Vehicle

ACRONYM	DESCRIPTION
ITS	Intelligent Transportation Systems
LAN	Local Area Network
LOS	Level of Service
LOSS	Level of Service of Safety
LPR	License Plate Recognition
LPT	License Plate Tolling
LUS	Lane Use System
MLFF	Multi-Lane Free-Flow
MOMS	Maintenance On-Line Management System
MPH	Miles Per Hour
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
MUTCD	Manual on Uniform Traffic Control Devices
MVRD	Microwave Vehicle Radar Detectors
NWP	Northwest Parkway
OCR	Optical Character Recognition
OHVMS	Overhead Variable Message Sign
RMS	Ramp Meter Station
RWIS	Road and Weather Information System
RTD	Regional Transportation District
SMVMS	Side-Mounted Variable Message Sign
SOV	Single Occupant Vehicle
SPF	Safety Performance Function
TCS	Toll Collection System
TEL	Tolled Express Lane
TOD	Time of Day
TTI	Travel Time Indicator
V-Toll	Video Toll
VHT	Vehicle Hours Traveled
VLAN	Virtual Local Area Network
VMS	Variable Message Sign
VMT	Vehicle Miles Traveled
VPC	Video Processing Center
VPD	Vehicles Per Day

ACRONYM	DESCRIPTION
VRH	Vehicle Registration Hold
VSL	Variable Speed Limit
VTMS	Variable Tolling Message Sign
WAN	Wide Area Network

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1. Introduction

1.1. Document Purpose

This document describes the Concept of Operations for the Tolled Express Lanes (TEL's) on Interstate 70 (I-70) from Interstate 25 (I-25) to Chambers Road (see Figure 1.1), denoted as the "I-70 East express lanes" hereinafter, from the perspective of the operator, the Colorado Department of Transportation (CDOT), the High Performance Transportation Enterprise (HPTE), and the users. The Concept of Operations is a first step that sets the stage for the remainder of the system development process and is used continuously to validate the system when it has become operational. Figure 1.2 demonstrates the relationship that the Concept of Operations maintains with the systems engineering process. Based on the systems engineering V-diagram and best development practices, the incorporation of the Concept of Operations at every phase of development assures that all goals are achieved.

The Concept of Operations answers the following questions about the new or existing system:

- ✓ **Who** are the stakeholders involved with the system?
- ✓ **What** are the known elements and the high-level capabilities of the system?
- ✓ **When** will activities be performed?
- ✓ **Where** are the geographical and physical extents of the system?
- ✓ **Why** will the system provide what the organization is missing?
- ✓ **How** are resources needed to design, build, or retrofit the system?

Additionally, this document identifies existing and future stakeholders responsible for managing transportation facilities and services in the project area and presents a shared understanding of the systems to be developed and how they will be operated and maintained. Expanding the capacity of I-70 East by adding Managed Lanes has been preliminarily identified as the Preferred Alternative in the Supplemental Draft Environmental Impact Statement. The proposed managed lanes incorporate tolling to manage demand and consequently improve travel-time reliability by providing better operations while maintaining priority use for express buses and carpools.

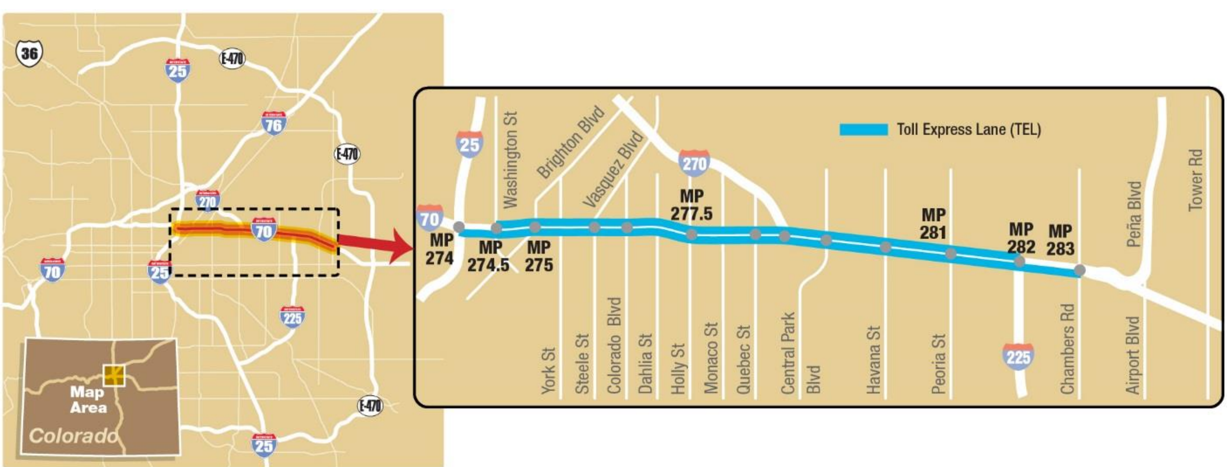


Figure 1.1: I-70 East Tolled Express Lanes Project Area

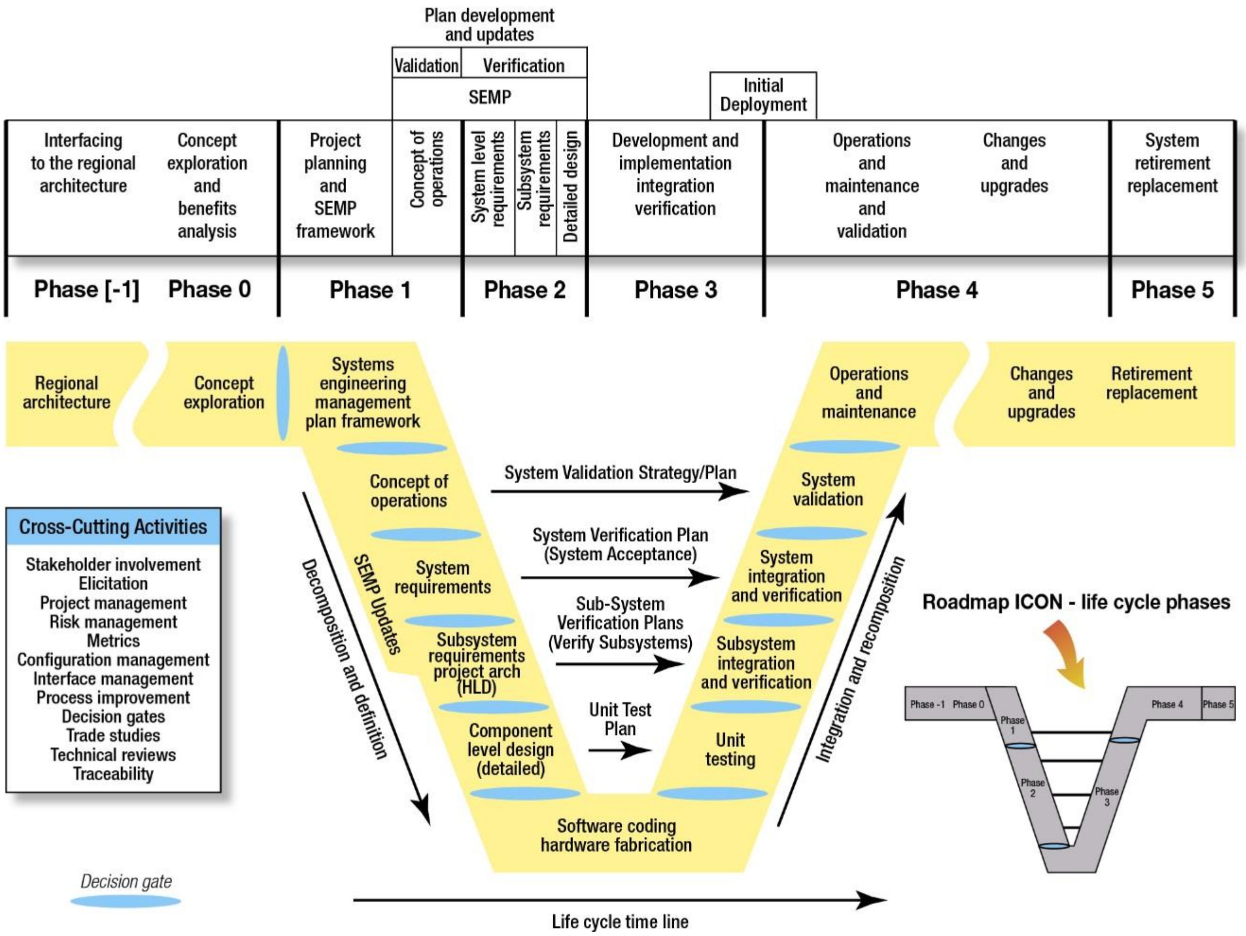


Figure 1.2: The System Engineering V-Diagram

This document is not intended to be a detailed functional and performance specification. It will form the basis of the functional and technical specifications documentation for development of the detailed design and, in the future, the implementation and contract documentation. Elements such as signing and striping (beyond basic concepts), implementation and maintenance, and incident management are more appropriately defined during subsequent phases and are expected to be completed outside of this document effort.

1.2. Goals and Objectives

The proposed I-70 East TEL's will offer more choices to commuters and make the best use of available freeway capacity. The project has several key goals that are similar to those of other recent managed lane/tolled express lane projects (e.g., the U.S. Highway 36 (US 36) Express Lanes Reconstruction project and the North I-25 Express Lanes Extension project from US 36 to 120th Avenue), including the following:

- **Improve overall corridor throughput.** TEL's will optimize flow within the facility. Active Traffic Management (ATM) helps reduce the frequency and duration of incidents across all lanes of travel. Together, these improvements enhance travel along the corridor for all roadway users.

- **Preserve capacity, provide more reliable travel time, and increase travel choices.** TEL's will allow the entering flow of vehicles to be managed and help provide higher travel speeds through the corridor.
- **Improve transit on-time performance.** Express lanes provide a means for Regional Transportation District (RTD) transit buses and Denver Regional Council of Governments (DRCOG) vanpools to achieve better on-time performance by removing them from the congestion in the general-purpose (GP) lanes and ensuring more reliable travel conditions in the express lanes.
- **Encourage carpooling and transit use.** Transit buses and eligible high-occupancy vehicle (HOV) users benefit from both the travel time savings as well as toll-free use of the express lanes.
- **Encourage further economic growth in the corridor.** The proposed concept provides a more efficient transportation system, thereby enhancing economic productivity and attractiveness for development.
- **Improve safety by reducing crashes.** The corridor concept includes an ATM solution designed to reduce primary and secondary collisions, which in turn not only improves safety but also enhances overall mobility in the corridor.

1.3. Project Scope and Concept Overview

According to the CDOT Express Lanes Policy Directive dated January 30, 2013, "... all projects seeking to build capacity improvements on the state highway system shall consider Express Lanes." This Concept of Operations pertains to the TEL's on I-70 East from I-25 to Chambers Road.

Due to funding constraints, the I-70 East proposed improvements will be completed in phases. Phase I involves reconstruction of I-70 to ultimate build between Brighton Boulevard and Quebec Street as well as widening to construct one new TEL in each direction east of Quebect Street to Chambers Road. Initially, the TEL's will include one painted, buffer-separated express lane in each direction. The future ultimate road template will include two express lanes in each direction. The project is being delivered as a Public Private Partnership (PPP) through a Design Build Finance Operate & Maintain (DBFOM) delivery approach. The PPP Developer will have responsibility for long term operations and maintenance (anticipated to be 30 years) of certain elements of the infrastructure. CDOT will operate and maintain the Electronic Toll Collection (ETC) and retain the associated revenue.

The eastbound TEL from I-25 to Brighton Boulevard will be created by repurposing the existing inside shoulders. At Brighton Boulevard, an ingress is provided for vehicles entering I-70 from I-25. An ingress/egress point will be located at the new interchange at Holly Street. The TEL will have egress at Peoria Street to provide access to Interstate 225 (I-225), Chambers Road, and Pena Boulevard. The TEL continues as a "bleed-out lane" to Chambers Road.

The westbound TEL will begin at I-225 through minor widening and repurposing of the left shoulder. The westbound TEL will have an ingress at Peoria Street to allow vehicles entering I-70 from I-225 to access the TEL. The westbound TEL has an ingress/egress point at Holly Street and an egress point at Brighton Boulevard to allow vehicle access to I-25. The westbound TEL will terminate at Brighton Boulevard, and then continues as a "bleed-out lane" to just west of I-25 (see Figure 1.1).

The TEL's are proposed to be accompanied by ATM as a safety and operations enhancement. The developer will be responsible for the design and construction of the new facility, as well as maintenance of the roadway, ATM, and Intelligent Transportation Systems (ITS) infrastructure. HPTE will be responsible for the management and operation of the TEL's, including the tolling system. At the time of this writing, the E-470 Public Highway Authority (E-470) serves as the ETC integrator and back office support to process transactions, collect tolls, and issue invoices.

The basic concept of how the I-70 East TEL's will be operated is outlined as follows:

- The I-70 East TEL's will be operated in accordance with prevailing federal law for interstate-based priced express lanes.
- At the time of this writing, all TEL's in Colorado utilize Time of Day (TOD) tolling. For the I-70 East TEL's, it is envisioned to utilize dynamic tolling that is responsive to changes in traffic conditions and where toll rates are set based on desired, pre-specified traffic parameters. The facility will open with dynamic pricing, unless determined otherwise by HPTE.
- As a goal, the express lanes will maintain a minimum free-flow speed of 45 mph and a daily average of 53 mph or better (corresponding with a Level of Service (LOS) rating of "C").
- Toll rates will vary to maintain the performance standards.
- The TEL's will be monitored and controlled by CDOT staff.
- The TEL's will be open to all eligible vehicles, and all vehicles (except those that are established as toll-exempt) will be required to pay the toll.
- Tolls will be collected electronically using Colorado interoperable transponders and license plate recognition systems. By federal law, national interoperable toll collection system(s) must be utilized by December 2016.
- All toll-exempt vehicles will be required to carry a non-revenue transponder.
- Transactions in the eastbound and westbound directions will be assembled as one zone (also known as a segment) from I-25 to Chambers Road.

The project will provide meaningful relief for one of the most congested corridor in the Denver metro area. The traffic volumes on the I-70 East corridor between I-25 and Chambers Road peak at 200,000 vehicles per day (two-way AADT). Implementation of the TEL will result in a more efficient use of the planned roadway capacity to improve traffic flow and reduce travel times in the corridor. In addition, the TEL's will provide more consistent transit travel times for the many express transit routes that currently serve the corridor.

Under the TEL's lane configuration, all eligible users—including HOVs with self-declaration transponders, registered hybrid vehicles, motorcycles, buses, and toll-paying single-occupant vehicles (SOV)—will be able to enter/exit the express lanes at designated ingress/egress points.

The following identifies the design and operational parameters for this Concept of Operations:

- **Location:** The I-70 East TEL's will be located on the inside of each direction of the I-70 general-purpose lanes, generally between the median barrier and the leftmost general-purpose lane.
- **Separation:** The express lanes will be separated from the general-purpose lanes by a four-foot painted buffer from I-25 to Quebec Street and a minimum two-foot (4-foot desirable) painted buffer from Quebec Street to Chambers Road.
- **Access:** Merge lane, weave lane, and weave zone with the general-purpose lanes will be the primary form of access to the express lanes.

- **Hours of Operation:** The express lanes will operate 24 hours a day, seven days a week. Closures will be conducted for periodic maintenance. The express lanes will be closed or open to all traffic for incident management purposes as defined in incident management protocol and policy.
- **Performance Objective:** Performance for the express lanes will be oriented toward minimum speeds, in accordance with federal law. No operational guarantee will be offered to customers. The express lanes will be managed to maintain a minimum desirable free-flow speed of 45 mph and an average free-flow speed of 53 mph or better (corresponding with an LOS C).
- **Use of Express Lanes:**
  - Single-occupant passenger vehicles may utilize the express lanes in exchange for payment of a dynamic toll. Trucks and multi-axle vehicles also may use the facility with toll payment and additional vehicle surcharge.
  - No tolls will be charged for RTD buses, carpools (HOV3+), or vanpools with self-declaration transponders; registered hybrids; motorcycles; and emergency responders.
- **Express Lanes Closure:** The express lanes will close periodically, during which time no vehicles may access the express lanes. Closure is authorized for non-critical maintenance, time-critical maintenance, and incidents.
- **Express Lanes Open to All Traffic (No Toll):** The express lanes will open to all traffic periodically, during which time all traffic will have access to the express lanes without tolls being applied. In all cases, the request to open to all traffic must derive from emergency responders and managers or be approved by HPTE.

1.4. Planned Future Revisions of this Document

The I-70 East TEL's will be built in phases. This document covers the Phase I concept of operations involving; full reconstruction to ultimate conditions for the segment from I-25 to Quebec Street and minor widening from Quebec Street to Chambers Road to accommodate a tolled express lane. It is recognized that the addition of another tolled express lane, a facility extension to Tower Road, construction of direct connections to and from the tolled express lanes at I-270, I-225, and Pena Bouelvard, and other improvements would occur in future phases. Therefore, it is envisioned that this Concept of Operations will be updated as appropriate to account for future extensions and modifications in the system.

1.5. Referenced Documents

- I-70 East Supplemental Draft Environmental Impact Statement, August 29, 2014
- I-70 East Final Environmental Impact Statement, anticipated in 2016
- I-70 East Record of Decision, anticipated in 2016
- Concept of Operations for North I-25 Express Lanes System, May 2013
- North I-25 Express Lanes Extension: Cost-Effective Multimodal Mobility Improvements for Metropolitan Denver, Colorado, Colorado Department of Transportation, October 2011
- Concept of Operations for the US 36 Managed Lane, Apex Design PC, 2011
- Manual on Uniform Traffic Control Devices (MUTCD), Federal Highway Administration, 2009
- A Policy on Geometric Design of Highways and Streets, 5th Edition, American Association of State Highway and Transportation Officials, 2004
- Highway Capacity Manual, Transportation Research Board, 2010
- Efficient Use of Highway Capacity Summary Report to Congress, American Association of State Highway and Transportation Officials, November 2010
- Highway Safety Manual, American Association of State Highway and Transportation Officials, 2010

2. Existing Conditions

I-70 East is a major transportation facility for the Denver metro area and the state of Colorado. In Colorado, I-70 runs east-west from border to border and provides connectivity between the Denver metro area, the Rocky Mountains, and the Eastern Plains. Nationally, I-70 begins on the east coast in Maryland and runs continuously west through Colorado to its termini in southwest Utah, where it junctions with Interstate 15 (I-15) and continues south and west to Los Angeles, California. In addition to significant employment centers along this facility that draw residents from all over the Denver metro area, I-70 is the major route between the Denver metro area and Denver International Airport. This results in high peak-hour demand that has increased the amount of congestion along the facility. As one of the most congested corridors in Colorado, projections of the future peak-hour highway conditions indicate increased congestion and delay within the corridor. Traffic volumes currently exceed what the highway system can accommodate, resulting in traffic backups onto local streets and travel-time delays.

I-70 is a fully access-controlled freeway, generally with six lanes from I-25 to Interstate 270 (I-270), eight lanes from I-270 to I-225, six lanes from I-225 to Peña Boulevard, and four lanes east of Peña Boulevard. Add/drop lanes and continuous acceleration/deceleration (auxiliary) lanes are provided between many of the interchanges for vehicles entering and exiting I-70. The speed limit along I-70 within the study area is 55 mph. The portion of I-70 from Washington Street to Colorado Boulevard is elevated. I-70 remains at grade from Colorado Boulevard to the eastern limit of the study area. The following sections describe in more detail the existing conditions along I-70 related to traffic operations, traffic safety, ITS, and regional tolling infrastructure.

2.1. Current HOV Operating Policy

There are currently no express lane facilities along the I-70 corridor inside or outside of the study area; however, HOV lanes do exist on other roadways within the Denver metro area. There is a mixture of express lanes, tolled and non-tolled HOV lanes, and TEL's on U.S. Highway 85 (US 85), US 36, and I-25 within the Denver metro area. On February 21, 2013, a resolution (TC-3052-3) was approved to implement an HOV 3+ policy on all TEL's in Colorado starting January 1, 2017. This new resolution will have an effect on the future operations of the TEL's with the I-70 East corridor.

2.2. Tolling Infrastructure (Existing)

As of May 2015, Figure 2.1 presents planned and existing toll facilities and TEL's in Colorado. Currently, there are two toll facilities: (1) the Northwest Parkway north of US 36, and (2) E-470 in the eastern portion of the Metro Area. All of the toll facilities and TEL's are interoperable with the automatic vehicle identification being branded as ExpressToll. The E-470 Public Highway Authority issues the transponders and manages all of the customer accounts for toll facilities. The following describes the electronic toll collection technologies and policies that are currently in place for each facility (see Figure 2.1 for planned and existing tolling infrastructure).

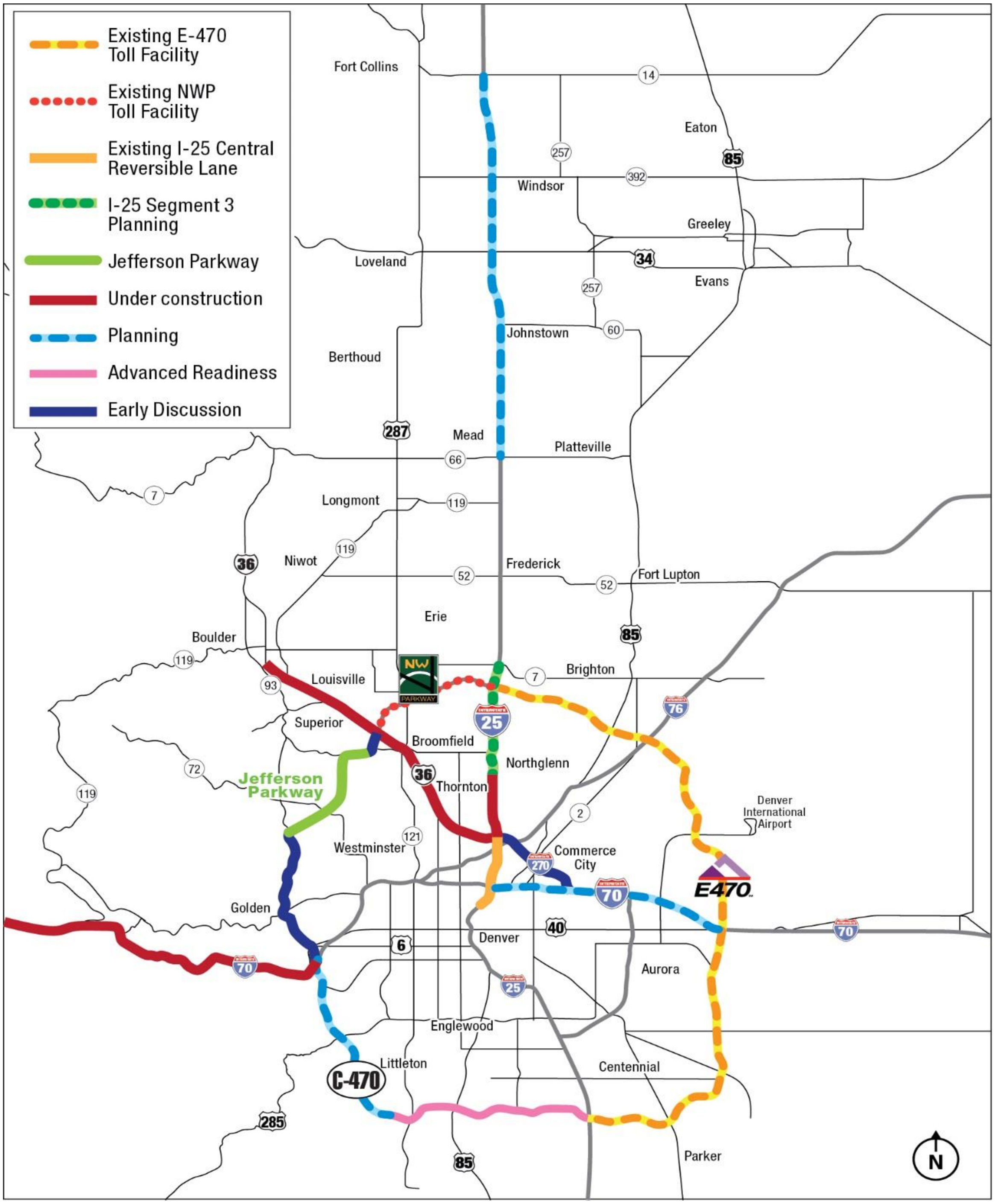


Figure 2.1: Denver Tolling Infrastructure (Existing and Planned, updated December 2014)

- **I-25 Express Lanes:** The I-25 Express Lanes facility is a two-lane reversible roadway that segregates vehicles into one lane for HOV vehicles and one lane for SOV vehicles at the tolling point. There is one gantry along the seven-mile segment where vehicle transponders are read and SOVs are assessed a toll. All vehicles in the HOV lane with transponders are read but are not assessed a toll, while all vehicles in the SOV lane are read and tolled. When E-470 converted their system to all-electronic, the option for license plate tolling (LPT) was added for SOVs. Access to the express lanes is controlled by automatic gates located along I-25 in the northbound and southbound directions. Three Variable Message Signs (VMSs) are located along North I-25 to provide southbound drivers with information regarding the I-25 Express Lanes (such as open/closed status and toll rate).

- **Northwest Parkway:** Northwest Parkway (NWP) is a privately owned and operated four-lane freeway toll facility that provides access from US 36 to I-25. All vehicles using the facility are assessed a toll, regardless of whether they are SOV or HOV. NWP is a 100-percent electronic toll collection facility. At the mainline, the same fee is charged for both transponders and LPT. A 10-percent discount is offered at the ramps for customers with transponders and for LPT customers who have an automatic billing account. Note that NWP's back office is used for processing LPT and E-470's back office for processing transponder tolling.
- **E-470:** E-470 is a privately owned and operated six-lane freeway toll facility that serves as a regional connector in the eastern portion of the Denver metro area. The facility provides direct access to I-25, I-70, C-470, and Peña Boulevard and connects with the Northwest Parkway. As with the Northwest Parkway, all vehicles using the facility are assessed a toll, regardless of whether they are SOV or HOV. Transponders are encouraged and read by electronic tolling equipment. For users without transponders, video license-plate tolling is used and the toll rate has a premium of approximately 25 percent over the transponder rate.

2.3. Existing ITS Infrastructure

There are various ITS components currently utilized along this segment of the I-70 corridor. These include:

- **Closed-Circuit Television (CCTV) Camera:** There are a total of nine existing CCTVs within the I-70 East corridor used by CDOT. They are located at I-25, York Street, Colorado Boulevard, I-270, Central Park Boulevard, I-225, Chambers Road, Airport Boulevard, and Tower Road (see Table 2.1 and Figure 2.2). The CCTV cameras are used for monitoring travel conditions in the corridor, such as weather conditions, accidents, traffic congestion, and other events. Video images also are shared with the public via the Internet (www.CoTrip.org) and television news outlets.

- **Variable Message Signs:** There are a total of six existing VMSs within the I-70 East corridor used by CDOT. Two are in the westbound direction and are located at approximately York Street and at Central Park Boulevard. The remaining four signs in the eastbound direction are located at approximately I-25, Washington Street, Steele Street/Vasquez Boulevard, and Tower Road (see Table 2.1 and Figure 2.2). VMSs are used for a wide range of purposes, including providing driver information regarding weather advisories, travel times, amber alerts, and construction and incident notifications.

- **Microwave Vehicle Radar Detector (MVRD):** There are a total of four existing MVRDs within the I-70 East corridor used by CDOT. Two are in the westbound direction and are located at approximately York Street and at Central Park Boulevard. The remaining two are in the eastbound direction, and are located at approximately Colorado Boulevard and Chambers Road (see Table 2.1 and Figure 2.2). MVRD, also referred to as side-fire radar, is used to measure volume, occupancy, speed, and classification in each lane of travel. A single unit generally can measure all lanes of travel in both directions, unless there is significant grade separation or obstructions. The data are used primarily for assessment and analysis of traffic conditions, both in real time and for studies. The data can be connected to other devices or alarms to trigger an action when volumes, occupancy, or speed extend beyond a predefined threshold.

- **Travel Time Indicator (TTI):** There are a total of eight existing TTIs within the I-70 East corridor used by CDOT (see Table 2.1 and Figure 2.2). A TTI is a toll tag reader that is utilized to help determine the travel time between two points by comparing the time it takes an individual toll tag to be read between two different toll tag readers. This information is used to determine an average travel time, which then is displayed on the COTRIP website and VMS signs within the travel corridor. There are two TTIs located at I-25 and I-70 and two located at Peoria Street. The other four are located at Central Park Boulevard, I-225, Quebec Street, and Tower Road.
- **Automatic Traffic Recorder (ATR):** There is one single existing ATR within the I-70 East corridor used by CDOT. It is located at approximately Colorado Boulevard (see Table 2.1 and Figure 2.2). The ATR is used to collect traffic data for eastbound I-70 exclusively. ATR stations are permanent counting stations that continuously collect vehicle volume, speed, and occupancy.
- **Road Weather Information System (RWIS):** There are two existing RWISs within the I-70 East corridor used by CDOT (see Table 2.1 and Figure 2.2). An RWIS measures atmospheric, pavement, and/or water-level conditions along roadways. The data obtained from an RWIS are used by CDOT to anticipate and prepare for upcoming weather events that might affect roadway operations or to determine roadway conditions during weather events. CDOT then can post that information to VMSs for the travelling public and can use it to assist with making decisions on plowing and de-icing operations during winter weather events.
- **Ramp Meter Station (RMS):** There are a total of eight existing RMSs within the I-70 East corridor used by CDOT (see Table 2.1 and Figure 2.2). There are existing RMSs in the westbound and eastbound direction at Central Park Boulevard, Havana Street, and Peoria Street. There are RMSs in the eastbound direction only at approximately Stapleton Drive and Quebec Street.
- **Fiber Backbone:** The existing communication network along the I-70 East corridor consists of shared resource 24-strand fiber optic backbone that extends the full length of the corridor (see Figure 2.3). Fiber laterals are used to connect the various ITS devices to the backbone. This allows devices that are installed along the corridor to have reliable, high-speed communications with the node building at the Colorado Transportation Management Center (CTMC), operated and maintained by CDOT ITS in Golden.

Table 2.1: Existing ITS Devices on I-70 East

ITS DEVICE	WESTBOUND	EASTBOUND	MEDIAN/OTHER	TOTAL
Closed Circuit Television Camera	—	—	9	9
Variable Message Sign)	2	4	—	6
Microwave Vehicle Radar Detector	2	2	—	4
Travel Time Indicator)	5	3	—	8
Automatic Traffic Recorder	—	1	—	1
Road Weather Information System	—	—	2	2
Ramp Meter Station	3	5	—	8
TOTAL ITS DEVICES	**12**	**15**	**11**	**38**

Figure 2.2: Existing ITS Devices on I-70 East

- **Other Communications Infrastructure:** ITS devices in the corridor are connected via the fiber optic backbone along I-70 (see Figure 2.3). This fiber optic backbone is currently limited to 24 strands of fiber and is leased for 20 years. Currently, there is insufficient fiber along I-70 to provide the communications required for all of the proposed ITS and ETC devices. Furthermore, given that the fiber is leased from a private entity, there is no opportunity for expansion within the current conduit. Therefore, additional conduit, fiber optic cable (minimum of 144 fiber optic strands), and associated equipment will need to be designed and constructed as part of the I-70 East Project.

Data are sent to and from field devices to the Node 2 regeneration building, the CTMC, and CDOT Region 1.

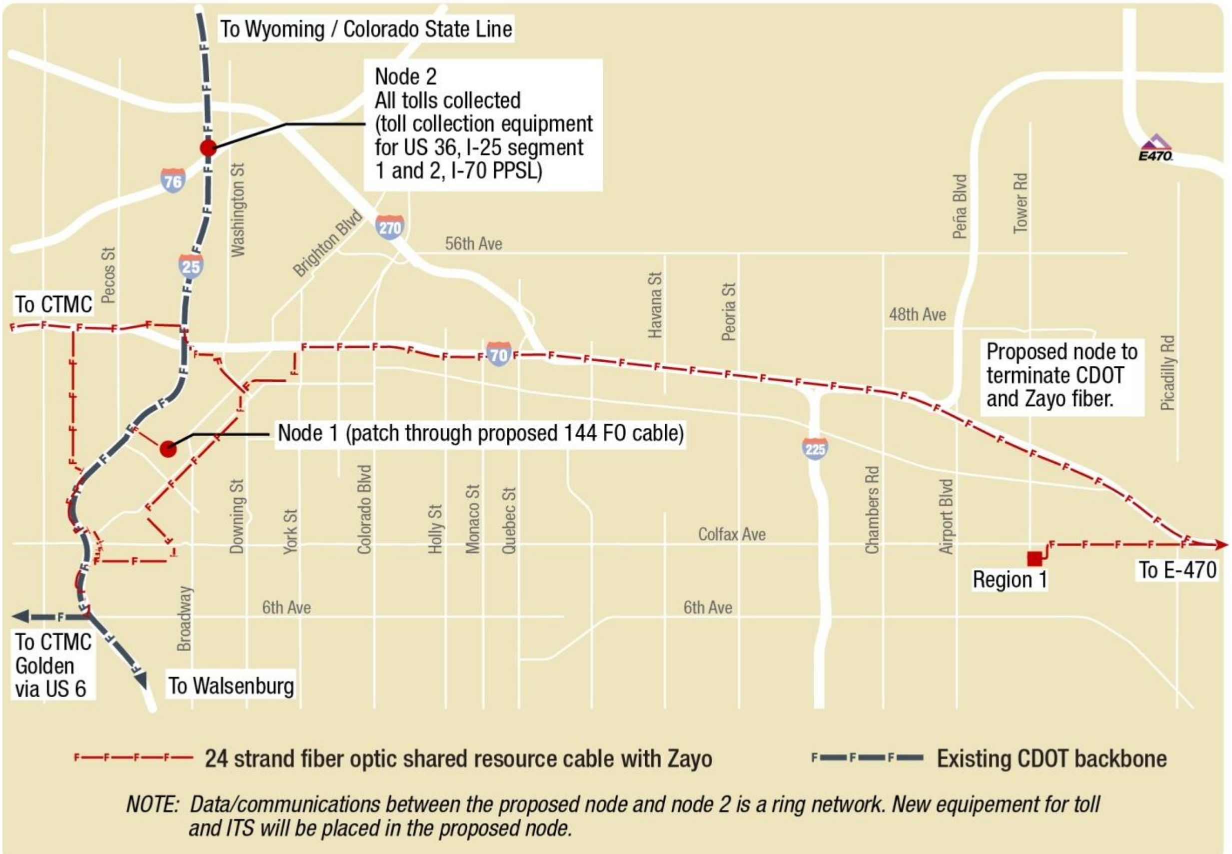


Figure 2.3: Existing Fiber Backbone

- **ITS Software:** There are several existing software programs used to assist with ITS infrastructure operations and maintenance. These software programs are described in the following chapters and briefly below:
  - ***Colorado Transportation Management Software (CTMS):*** CTMS is a customized software application that integrates various ITS devices into a single program. The software resides at the CTMC and is used to post messages to the various VMSs. The program also is used to collect and assemble the TTI, MVRD, RMS, and RWIS data, and then disseminate this information to the travelling public.
  - ***Camera Cameleon ITS Client:*** The Camera Cameleon ITS client is a software program used to view and control CCTV surveillance cameras. There are client versions of the software at CTMC, CDOT, and other agencies.
  - ***Camera Cameleon HOV ITS Client:*** Camera Cameleon HOV ITS Client software is a version of Camera Cameleon customized for the I-25 Express Lanes. This software resides at CDOT and the Node 2 regeneration building. The software controls the HOV VMSs and automatic gates, including posting the toll rates to the HOV VMSs.

2.4. Roles and Responsibilities

There are many stakeholder groups that will have a role in the design, construction, financing, operations, and maintenance of the proposed express lane facility. These groups, along with their responsibilities relating to ITS and tolling, are discussed below:

- **HPTE:** HPTE would have the responsibility for managing and operating the TEL's, including collection of the toll revenue and all decisions regarding the express lanes operational status.
- **CDOT ITS:** The CDOT ITS branch would operate and maintain the existing and proposed ITS infrastructure. This includes many of the ITS elements discussed above, including ATM systems.
- **CDOT Headquarters:** CDOT Staff Traffic and Safety oversees all safety programs throughout the state and would evaluate the safety performance of both the TEL's and the general-purpose lanes in the corridor.
- **CDOT:** CDOT will contract to a private Developer the roadway maintenance of the TEL's and the general-purpose lanes, including signage and striping. CDOT will procure the design and construction of the project through a design build finance operate and maintain contract. Most of the operations and routine and life cycle maintenance requirements will be transferred to a Private Developer for an anticipated 30 year term.
- **Regional Transportation District:** RTD provides transit service in the corridor. Coordination with RTD will be necessary to ensure that the proposed project is consistent with the needs of transit vehicles.
- **E-470:** Through an agreement with HPTE, the E-470 Public Highway Authority would serve as the ETC system integrator responsible for design and construction of the tolling equipment. E-470 currently provides back-office support for HPTE for the I-25 Express Lanes and it is expected that they would have a similar role for the I-70 TEL's.
- **Denver Regional Council of Governments:** DRCOG will be involved as the Metropolitan Planning Organization (MPO) for the project.
- **Federal Highway Administration:** Since I-70 is part of the United States Interstate System, FHWA will have input into the final design of the facility and ongoing validation of performance requirements under MAP-21.
- **Law Enforcement Agencies:** The Colorado State Patrol (CSP) will have a critical role of providing enforcement along the facility to ensure safe operations and compliance with HOV occupancy requirements. Enforcement of the general-purpose lanes would be coordinated between CSP, the City and County of Denver, and the City of Aurora. HPTE would likely modify their current CSP agreement to provide HOV enforcement for the express lanes.

2.5. Traffic Characteristics

2.5.1. Existing footprint

I-70 is a fully access-controlled freeway, generally with six lanes from I-25 to I-270, eight lanes from I-270 to I-225, six lanes from I-225 to Peña Boulevard, and four lanes east of Peña Boulevard (see Figure 2.4). Add/drop lanes and continuous acceleration/deceleration (auxiliary) lanes are provided between many of the interchanges for vehicles entering and exiting I-70.

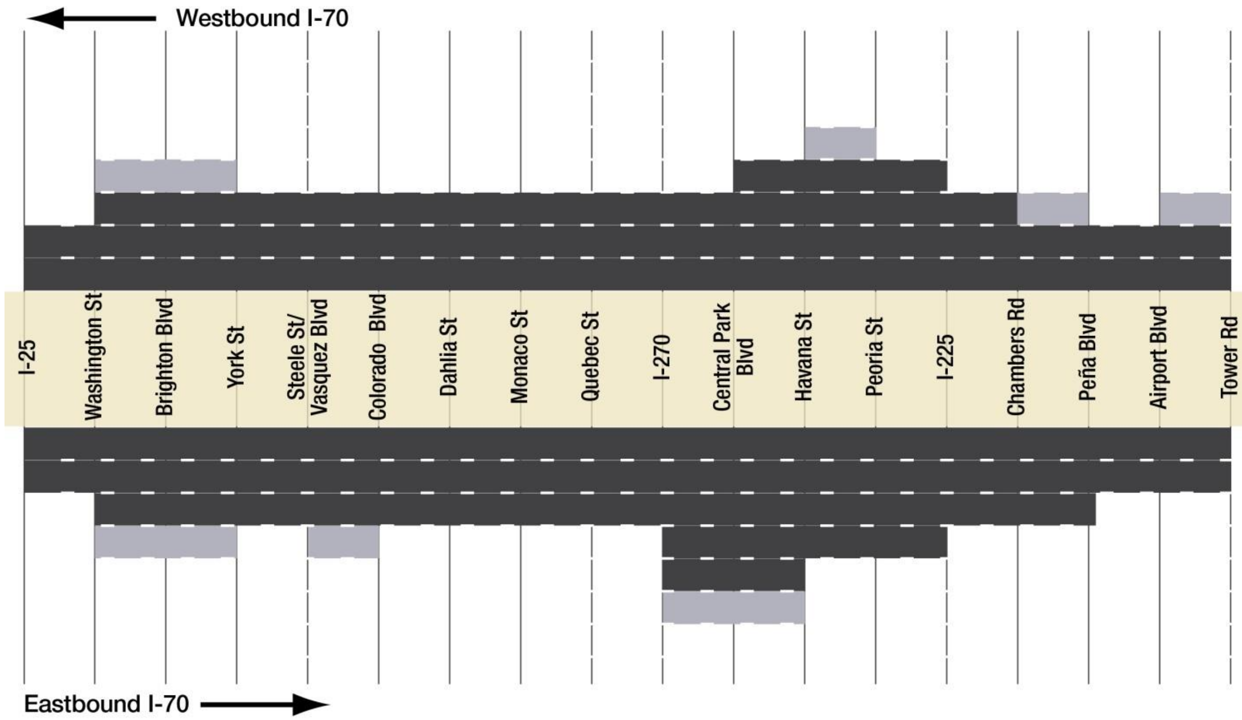


Figure 2.4: Existing Conditions Number of Lanes

2.5.2. Traffic operations analysis

An existing conditions operational analysis was completed to determine baseline performance within the study area and to understand how the highway is operating. The following performance measures provide a detailed analysis of the overall operations of the highway and local street system:

- I-70 Traffic Volumes
- I-70 Average Travel Speeds
- I-70 Vehicle Miles Traveled (VMT) (I-25 to Tower Road)
- I-70 Vehicle Hours Traveled (VHT) (I-25 to Tower Road)
- I-70 Travel Times (I-25 to Tower Road)

2.5.2.1. I-70 existing traffic volumes

Figure 2.5 shows the existing directional daily and peak period (5:00 a.m. to 11:00 a.m. and 2:00 p.m. to 8:00 p.m.) traffic volumes based on the output from the calibrated DynusT sub-area existing conditions traffic demand model using 2012 to represent existing conditions. The data represent an equilibrium condition or average traffic flow over various typical traffic conditions.

Generally, eastbound I-70 volumes entering the study area from the west side of I-25 are just under 40,000 vehicles per day (vpd), since there are only two lanes on I-70 at this point. The merging traffic from I-25, Washington Street, and Brighton Boulevard results in a rapid increase of more than 40,000 vpd, to a total of 80,000 vpd before reaching the York Street interchange. Eastbound volumes generally decrease at each subsequent interchange up to Central Park Boulevard, where there are approximately 65,000 vpd. The merge with I-270 results in traffic volumes increasing again by nearly 50,000 vpd, resulting in a directional high of nearly 115,000 vpd. East of this merge, volumes begin to decrease at each interchange, with significant diverging volumes at Chambers Road and Peña Boulevard. East of Peña Boulevard, I-70 has only two eastbound lanes and volumes are between 25,000 and 35,000 vpd.

Westbound I-70 entering volumes at Tower Road are slightly greater than 30,000 vpd. The westbound volumes rapidly increase to more than 75,000 vpd due to the Peña Boulevard merge, decrease to approximately 50,000 vpd at the I-225 diverge, but immediately increase to more than 90,000 vpd due to the I-225 merge. Westbound volumes reach a high of about 105,000 vpd just before the I-270 diverge, which results in a decrease of more than 40,000 vpd. West of the I-270 diverge, volumes show a pattern of generally increasing at each interchange up to the I-25 diverge, where traffic decreases by about 30,000 vpd, and about 40,000 vpd continue westbound past I-25, where there are only two lanes on I-70.

The peak-period traffic volumes follow a similar pattern as the daily volumes. In general, PM peak-period traffic is higher than the AM levels. The highest volumes are between I-270 and I-225.

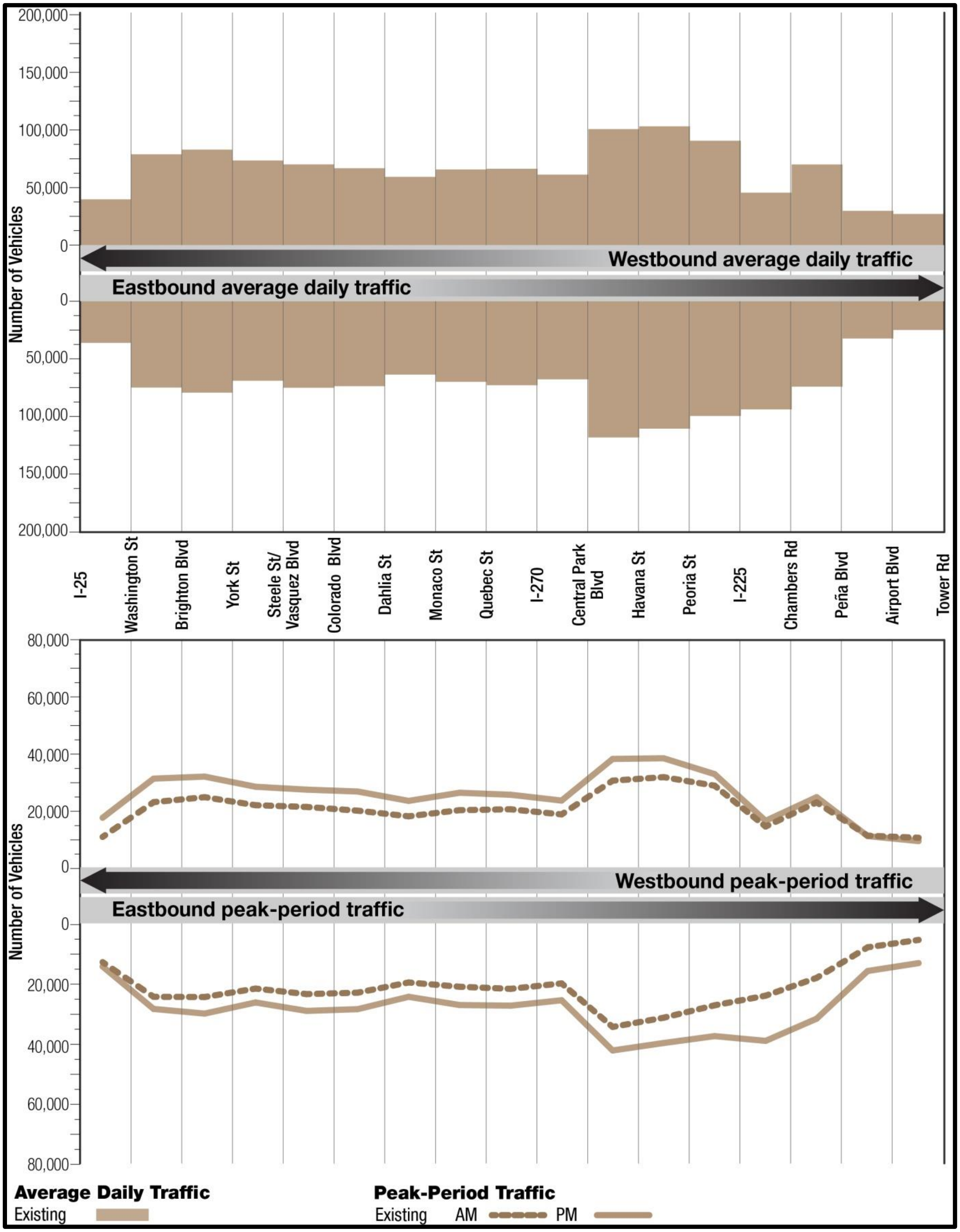


Figure 2.5: Existing Traffic Volumes (2012)

2.5.2.2. I-70 existing average travel speeds

DynusT software produces congestion maps, also known as “heat diagrams,” based on the average travel speeds (see Figure 2.6). The diagrams are called “heat diagrams” because they use colors to visually depict the travel speed conditions expected for a given time of day and a location on the roadway. Free-flow speeds (no congestion) are depicted in dark blue (cool temperatures) and low travel speeds (heavy congestion) are displayed in dark red (hot temperatures). These diagrams identify areas of congestion, as well as the duration and length of lower travel speeds.

Figure 2.6 provides an example of a typical heat diagram for eastbound traffic on I-70. The map along the bottom of the figure can be used to identify the location of congestion and the time scale on the left vertical axis represents trip starting times. The scale on the right side indicates the average speed of the vehicles as depicted with the colors of the heat spectrum. The figure is read by starting at the left edge (right edge for westbound maps) based on the starting or departure time of the trip in question and tracing the path of the vehicle to the right (toward the left for westbound trips) to determine the expected trip travel speeds between I-25 and Tower Road.

The average speeds for eastbound and westbound I-70 are shown in Figure 2.6. The figure shows eastbound congestion between Brighton Boulevard and York Street during the morning and evening peak periods. This congestion is due to the closely spaced merge/diverge areas for I-25, Washington Street, Brighton Boulevard, and York Street. Slowing speeds and congestion also are present during the peak periods of the day on the segment near I-270 and I-225. This is consistent with the heavy amount of traffic entering and exiting at these freeway-to-freeway connections. Overall, there is more eastbound congestion during the evening peak period than the rest of the day. Between the hours of 7:00 a.m. and 7:00 p.m., eastbound speeds typically remain at 45 mph or lower.

Figure 2.6 also shows westbound congestion between Peña Boulevard and the I-270 interchanges during the morning peak period. This area also has pockets of speeds below 50 mph for a majority of the day. Again, this congestion is consistent with the heavy amount of merging and diverging traffic associated with these freeway-to-freeway connections. Westbound I-70 shows congestion between Colorado Boulevard and York Street during the peak periods of the day due to the close spacing of the interchanges in this area.

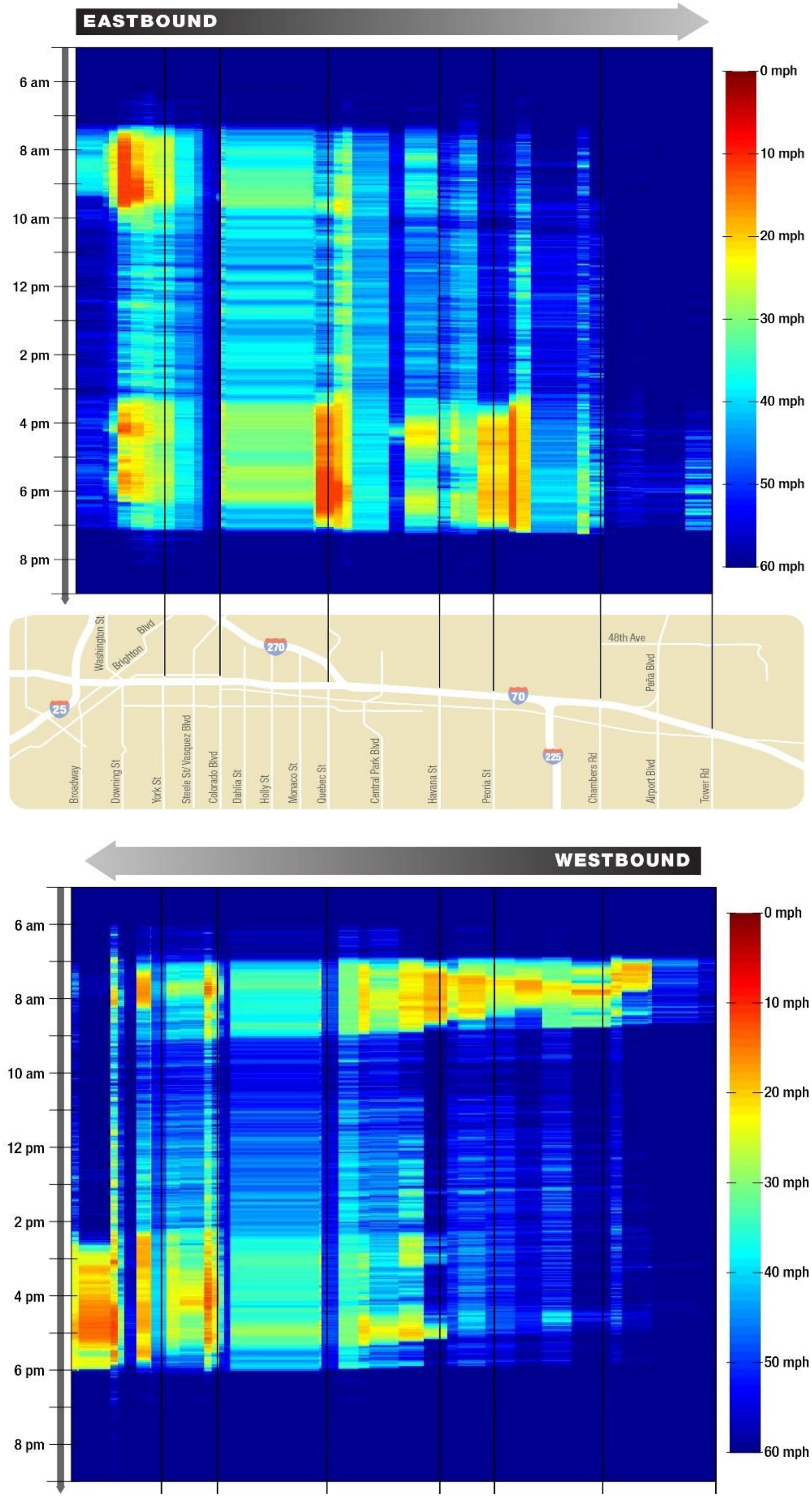


Figure 2.6: Exisiting Conditions—I-70 Eastbound Average Speeds

2.5.2.3. Existing vehicle miles traveled

Daily VMT for all trips within the sub-area and those using only I-70 itself are displayed in Figure 2.7. There are more than 15.8 million miles traveled each day on all roadways within the sub-area with a little more than 10 percent of this occurring on the portion of I-70 that is between I-25 and Tower Road.

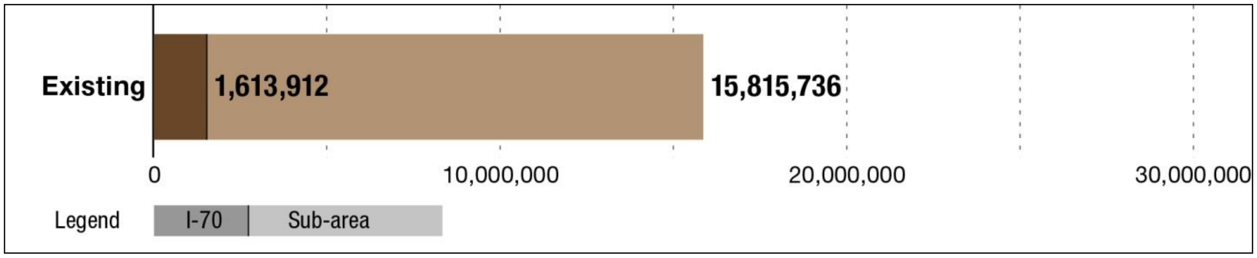


Figure 2.7: Existing conditions—Vehicle Miles Traveled

2.5.2.4. Existing vehicle hours traveled

Figure 2.8 displays daily VHT for the entire sub-area as well as I-70 within the study area. All of the trips in the sub-area total a little more than 0.5 million hours of travel each day, with the trips on I-70 (between I-25 and Tower Road) making up about 7 percent of this total.

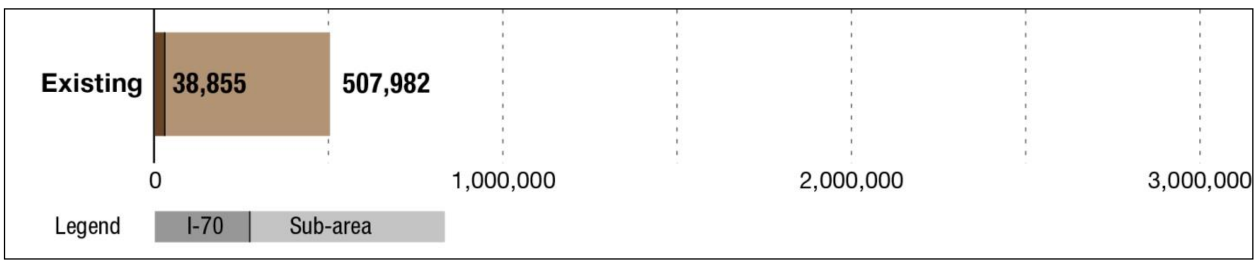


Figure 2.8: Existing conditions—Vehicle Hours Traveled

2.5.2.5. Existing I-70 travel times

Existing travel times for eastbound and westbound I-70 between I-25 and Tower Road (a distance of about 12 miles) are shown in Figure 2.9. The travel times assume no incidents during the peak periods. The introduction of an incident—such as a crash, stalled vehicle, debris on the roadway, the presence of slow moving vehicles, or inclement weather conditions—can have significant impact on the travel times. Thus, travel times are variable, and it is likely the actual travel times will fluctuate widely from day-to-day depending on traffic volumes, roadway conditions, possible incidents, and weather conditions.

It takes slightly longer than 12 minutes to travel eastbound or westbound between I-25 and Tower Road at free-flow speeds. The same eastbound trip can take approximately 21 minutes during the morning peak period and almost 27 minutes in the evening peak period, respectively, or between 75 percent and 125 percent longer than free-flow travel. In the morning and evening peaks, the westbound trip can take nearly 25 minutes ,or more than double longer than free-flow travel times.

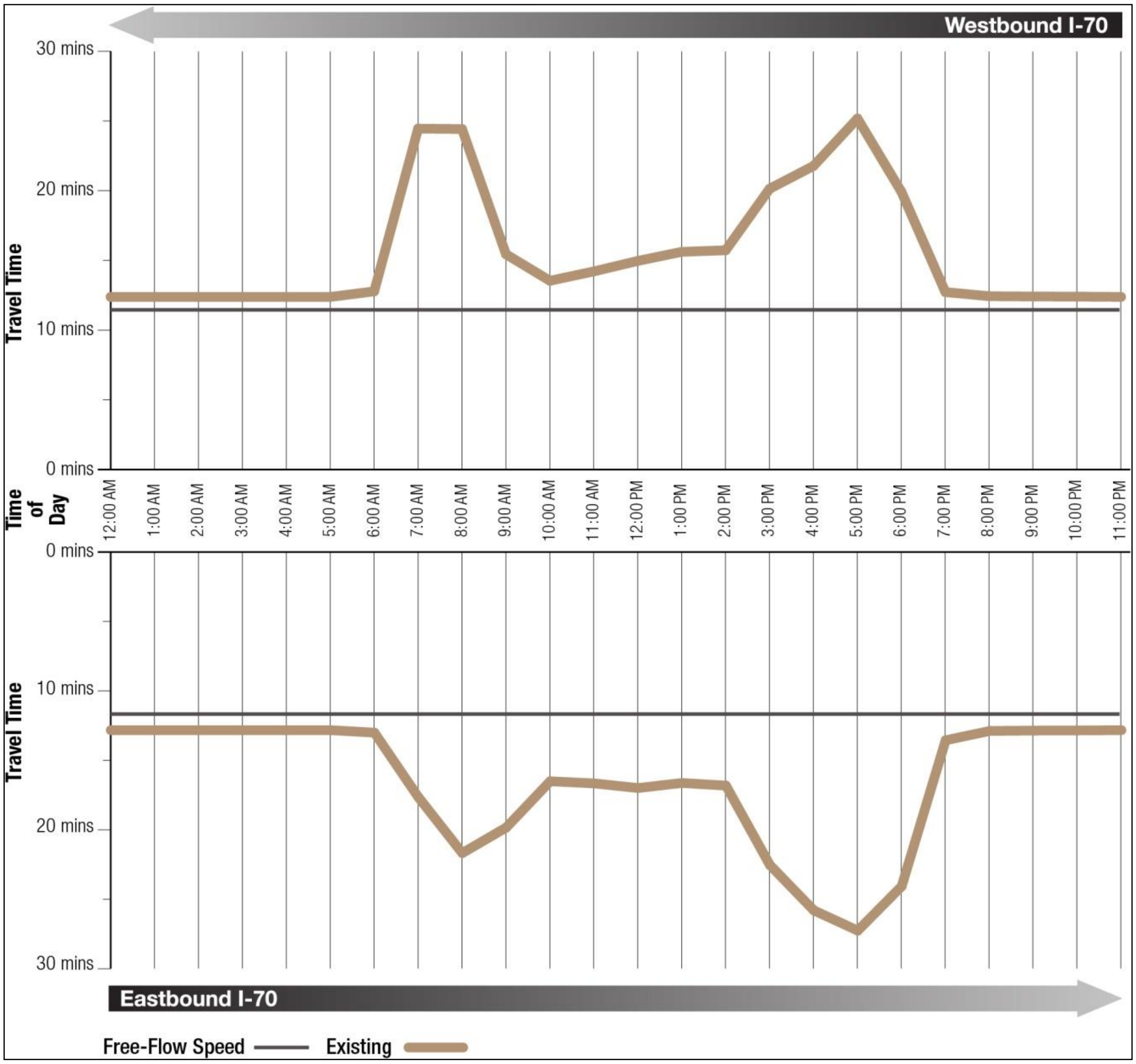


Figure 2.9: Existing Conditions—I-70 Travel Times

2.5.2.6. Existing (2012) conditions summary

The existing condition analysis for I-70 indicates the following:

- I-70 generally has higher eastbound daily and peak-period volumes.
- I-70 (between I-25 and Tower Road) accounts for approximately 10 percent of the sub-area VMT and about 8 percent of the sub-area VHT.
- The westbound travel time from Tower Road to I-25 is about 25 minutes during peak periods, compared to a free-flow travel time of about 12 minutes.
- Eastbound travel during the morning peak period is approximately 21 minutes and nearly 27 minutes during the evening peak period, compared to a free-flow travel time of about 12 minutes.
- Congestion on I-70 typically is confined to the areas near major merge and diverge movements (freeway-to-freeway interchanges) and in the areas where there are closely spaced interchanges.

- Eastbound I-70 speeds typically remain above 30 mph for the majority of the day.
- Westbound I-70 speeds tend to remain above 30 mph for most of the day. Overall, westbound I-70 has more periods with speeds below 30 mph than eastbound I-70.

2.5.3. Existing (2012) safety concerns

Existing traffic safety concerns within the project study area were documented in CDOT's *I-70 East Corridor EIS Safety Evaluation* (CDOT, 2004) and *Safety Evaluation Addendum: I-70 Corridor Plan* (CDOT, 2013). This study analyzed crash history for a three-year period (July 1, 2009, through June 30, 2012). During this time period, a total of 2,872 crashes were reported, with 309 causing injuries, and seven resulting in fatalities.

Of the total crashes reported, 63 percent (1,804) were on I-70 and 37 percent (1,068) were on I-70 ramps and crossroads. In both cases rear-end and sideswipe crashes were the predominant types. The predominance of rear-end and sideswipe crashes is indicative of corridor-wide congestion and inadequate auxiliary lanes, tapers, or pavement markings. Crash classifications for the mainline as well as ramps and crossroads are shown in Figure 2.10, below.

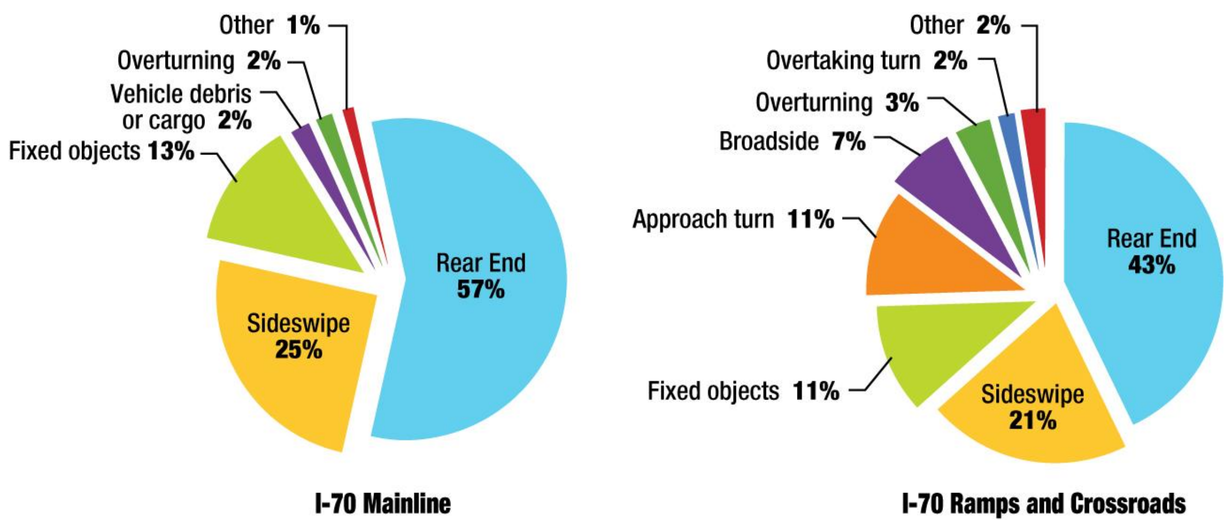


Figure 2.10: Existing conditions—Types of crashes in the project area

The I-70 corridor crash rates also were compared to a typical urban six-lane freeway to determine the level of service of safety (LOSS) rating by highway segment. Table 2.2 displays the results of the LOSS comparison for the I-70 corridor. The frequency of crashes is higher than expected (LOSS III or IV) for the segments at York Street, Steele Street, and Colorado Boulevard, with the Colorado Boulevard segment being the only one rated LOSS IV. This indicates that mainline safety performance is not as good when interchanges are closely spaced with short auxiliary lanes and ramps that require drivers to make significant speed changes within a short distance.

Table 2.2: Existing conditions—LOSS Comparison for Mainline I-70 Total Crashes

SECTION	INTERCHANGE	LOSS[1]
1	Washington St	LOSS II
2	Brighton Blvd	LOSS II
3	York St	LOSS III
4	Steele St/Vasquez Blvd	LOSS III
5	Colorado Blvd	LOSS IV
6	Dahlia St/Holly St/Monaco St	LOSS II
7	Quebec St/I-270	LOSS II
8	Havana St	LOSS II
9	Peoria St	LOSS II
10	I-225	LOSS I
11	Chambers Rd	LOSS II
12	Airport Blvd	LOSS II

(Source: CDOT's I-70 East Corridor EIS Safety Evaluation (2004) and Safety Evaluation Addendum: I-70 Corridor Plan, 2013).
[1]*LOSS I—indicates low potential for crash reduction; LOSS II—indicates better-than-expected safety performance; LOSS III—indicates less-than-expected safety performance; LOSS IV—indicates high potential for crash reduction*

Figure 2.11 depicts the Safety Performance Function (SPF) for total accidents calibrated specifically for urban six-lane freeways. Data for three years of accident history (averaged together) on I-70 has been split into separate segments and plotted for evaluation. The SPF total (see Figure 2.11) analysis describes the magnitude of the safety problem from a frequency and severity standpoint.

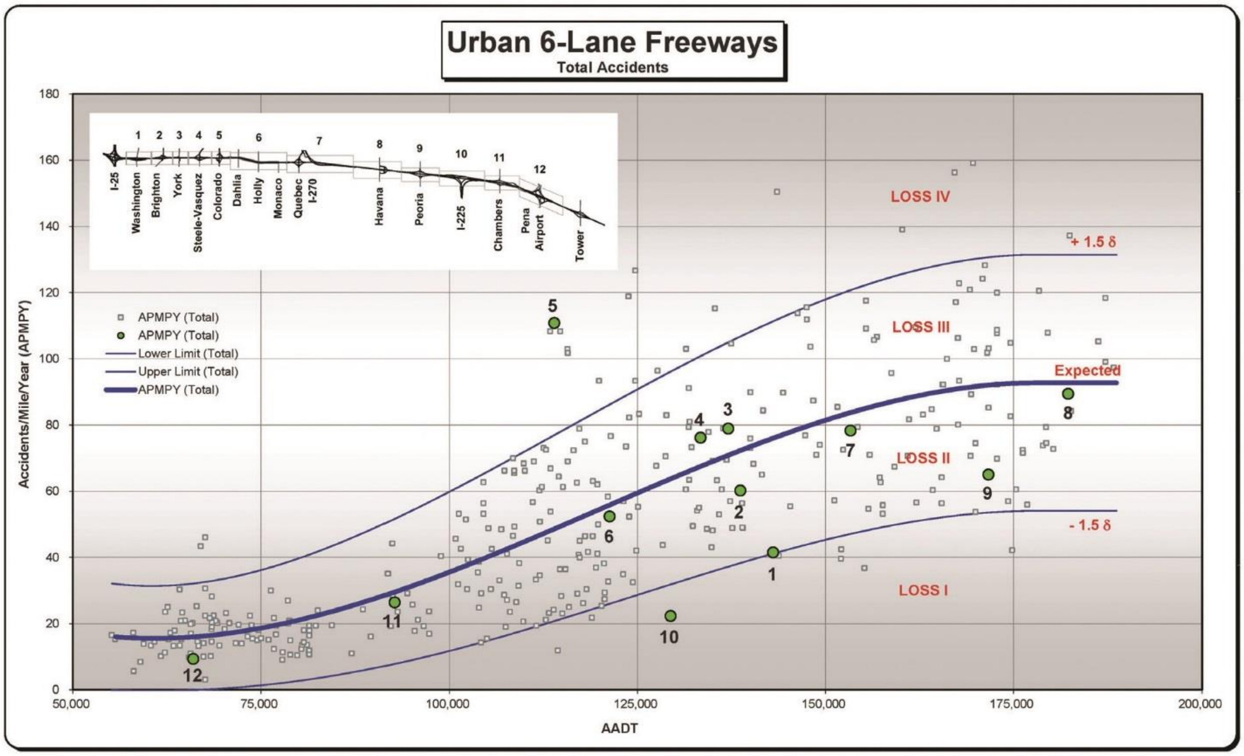


Figure 2.11: SPF total

From Figure 2.11 and Table 2.2, one can observe that only one I-70 segment is LOSS IV (high potential for accident reduction), two are LOSS III (less than expected safety performance) and eight are LOSS II (better than expected safety performance).

The general observation that can be made from these results is that the safety performance of the mainline tends to be better where interchanges are more widely spaced, where adequate auxiliary lanes are provided and (as is the case at Monaco Street/Holly Street/Dahlia Street) where a collector-distributor configuration is used. The mainline safety performance is not as good where the intersections are closely spaced, where auxiliary lanes are short and where ramps have characteristics which require vehicles using them to make large speed changes in a short distance.

2.6. Phase 1 Improvements and Expected Future Safety Conditions

Several of the I-70 East project planned improvements are specifically aimed at improving safety and reducing crashes. Specifically, the improvements that address safety include:

- Improved shoulders (both left and right side of highway)
- Improved interchange spacing
- Improved merge/diverge areas

Current conditions on I-70 East within the project limits include inadequate shoulders on both the eastbound and westbound sides of the highway in the section between Brighton Boulevard and Quebec Street. As part of the planned improvements, the highway will be expanded to widen the shoulders to provide more room for drivers to recover if they depart from the travel lanes. The improved shoulders also will provide a safer place for broken down vehicles to exit from the travel lanes and reduce the exposure to traffic conditions.

The planned improvements also include improved spacing between interchanges to better adhere to FHWA recommended practices. This includes the elimination of the York Street interchange, which currently is located in an area that did not allow for adequate acceleration and deceleration lanes to be developed. The Steele Street/Vasquez Boulevard and Colorado Boulevard interchanges have been modified to become a split diamond configuration. This includes the elimination of some loop ramps with short acceleration and deceleration lengths. In addition, a new interchange will be constructed at Holly Street, which allows for the elimination of the very short merge/diverge areas between the existing frontage road system (north and south of I-70) and the Colorado Boulevard and Quebec Street interchanges.

Another design improvement is using a design speed of 60-70 mph for the I-70 East phase I project. The increase in design speed will help provide additional safety elements aimed to help reduce the frequency and severity of accidents on I-70 East. Overall, the planned improvements to I-70 will create longer acceleration and deceleration lanes and lengthen the merge/diverge areas, which should result in less congestion on I-70 and fewer crashes. Table 2.3 shows the existing traffic crashes, the 2035 predicted No-Action Alternative traffic crashes, and the 2035 predicted Phase 1 traffic crashes.

Table 2.3: Predicted Safety Conditions

	EXISTING		2035 NO ACTION		2035 PHASE 1	
DESCRIPTION	**TOTAL CRASHES**	**SEVERE CRASHES**	**TOTAL CRASHES**	**SEVERE CRASHES**	**TOTAL CRASHES**	**SEVERE CRASHES**
I-70 Mainline	720	182	1,186	253	901	226
Ramp	73	16	126	25	111	24
Ramp Intersections	156	34	240	56	170	41
Intersection with 46th Avenue	11	4	16	6	11	4
Total Crashes Per Year	**960**	**236**	**1,568**	**340**	**1,193**	**295**

3. Project Needs

This section describes what is needed to meet project goals and to elicit requirements for the system. To achieve project goals discussed in Section 1.3, the primary tolling goals are as follows:

- Maximize use of available capacity
- Minimize revenue loss
- Provide net positive revenue after operations, enforcement, and maintenance
- Meet driver expectancy related to trip reliability
- Maintain consistency with existing toll facilities
- Maximize enforcement efficiency
- Provide seamless toll collection

3.1. Operational Needs

Efficient operation of the system is critical to the success of the express lanes in providing improved and reliable travel times for all users. As a result, the system will need to incorporate the following operational needs:

- Provide service 24 hours a day and seven days a week, with necessary periodic closure for level I/II maintenance as detailed in the maintenance management plan.
- Effectively accommodate various user classes, including:
    - Transit vehicles
    - Eligible HOV users (to conform with possible changes in HOV policy)
    - Toll-paying users
    - Motorcycles
    - Emergency response vehicles
    - Courtesy patrols
- Provide effective ingress and egress points
- Allow for efficient snow removal
- Effectively manage accidents in the express lanes
- Effectively manage accidents in the general-purpose lanes
- Effectively handle enforcement in the express lanes (including occupancy and lane diving)
- Allow for maintenance (roadway/ITS/tolling/ATM)

3.2. Enforcement Needs

Effective enforcement is critical to the success of the express lanes. Law enforcement personnel will need to have the ability to properly enforce the facility by having safe, effective locations to identify violations and issue citations. This can be accomplished using technology known as mobile enforcement readers and enforcement beacons. Potential technology for automated HOV enforcement will be discussed in this document.

3.3. Technological Needs

The proposed system also must satisfy several technological needs, including:

- Users must be detected and identified by the system to assess tolls
- Toll tag readers must be multi-protocol and read both the Title 21 and ISO 18000-6C protocols
- The technology needs to account for both HOV and SOV
- The system will need to integrate with other existing express lane protocols on I-25, E-470 and US 36
- Effective ITS subsystems are necessary to support tolling operations
- Effective ITS subsystems are needed to support traffic management in express lanes and adjacent general-purpose lanes
- Adaptability to account for new technology
- Ability to be expanded for future 2nd TEL and reconstruction to the ultimate template east of Quebec Street

4. Tolling Strategies

4.1. Transponder use

In addition to the one-state sticker tags, switchable transponders are made available to allow drivers to self-declare their occupancy status as SOV or HOV users. This allows the tolling system to recognize the occupancy status of vehicles that are read.

Vehicles without a transponder will be considered SOV users regardless of their occupancy status. Video License Plate Tolling will accommodate those vehicles and an invoice will be mailed to vehicle owners. Vehicles with a sticker tag will be considered SOV users regardless of their occupancy status and will be assessed the Automatic Vehicle Identification (AVI) toll rates.

4.1.1. Regional Consistency

The system of tolling in the Denver metro area is intended to be consistent among the tolled corridors. The system proposed for I-70 East TEL's will be required to be compatible and consistent with the tolling systems used on I-25, US 36, and E-470.

4.1.2. Legacy toll tag

Legacy toll tags are hard case transponders that typically attach to the inside of a vehicle's windshield. Each transponder is distinctly set with a unique electronic signature that is linked to a specific user account. These tags are read by roadside readers to identify the user and record a transaction. The hard case transponders used in Colorado are 3 inches by 3.5 inches and run on batteries.

Another type of transponder used in Colorado is a sticker (see Figure 4.1). Sticker transponders are smaller, less expensive ($1 to $2, as compared to $20 per unit for the hard-case transponder), and do not require a battery. These tags are typically mounted on a vehicle's windshield. Heavy vehicles may mount sticker-tags on their license plate due to the height of the vehicle.

Figure 4.1: Sticker ExpressToll Tag

In 2012, E-470 switched the standard transponders for Colorado to a sticker transponder using an open protocol tag known as ISO 18000-6C (often referred to simply as "6C"). From a national perspective, there are six main transponder protocols used across the country (see Figure 4.2).

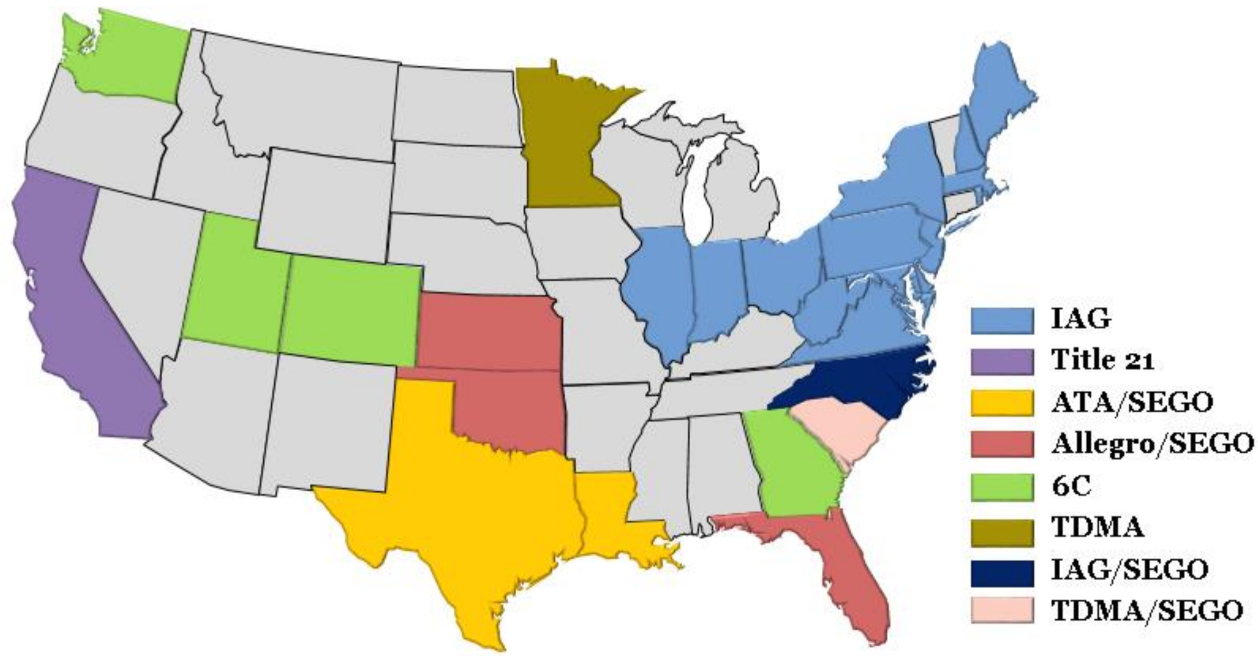


Figure 4.2: Transponder Protocols Across the U.S.

4.1.3. Switchable toll tag

Switchable transponders allow for separate declaration switches for different exempt statuses (SOV; HOV with two or more people occupying the vehicle [HOV 2+]; HOV with three or more people occupying the vehicle [HOV 3+]). Switchable toll tags can be two-state (i.e., HOV and non-HOV) or tri-state (i.e., SOV, HOV 2+, and HOV 3+). Figure 4.3 shows the Utah Express Pass tag that has the ability to be turned on and off depending upon vehicle occupancy.

Source: http://www.udot.utah.gov/expresslanes/

Figure 4.3: Utah Express Pass Tag

Hard case tri-state transponders with a switching mechanism already have been deployed on the Interstate 10 (I-10) and Interstate 110 (I-110) Express Lanes in Los Angeles and on the Interstate 495 (I-495) Express Lanes in Northern Virginia. The California FasTrak Title 21 compliant multi-mode hard case transponder allows users to perform self-declaration of HOV status (SOV, HOV 2+ and HOV 3+).

The Colorado switchable tag is two state (shown in Figure 4.4, below). It switches between two different IDs each corresponding to SOV or HOV and includes the following features:

- High speed read/write, high performance
- Sliding panel switches tag from one account status to another using dual mode

- Suitable for Electronic Toll Collection and High-Occupancy Toll (HOT) lane applications
- Passive, no battery
- Slim, modern design
- Interior windshield mounted
- Flexible branding options, custom tag case colors available

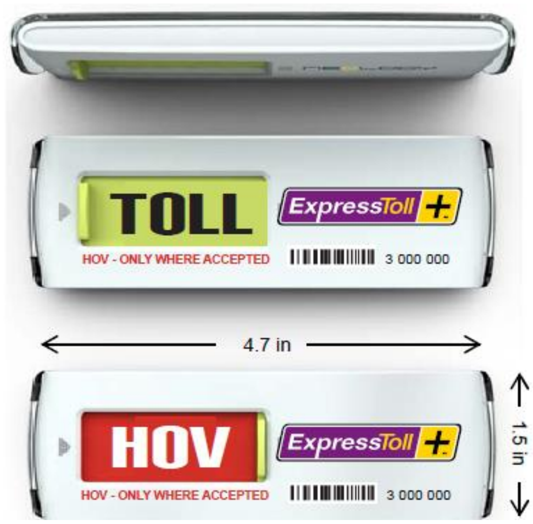


Figure 4.4: Colorado ExpressToll-Branded Switchable Transponder

4.1.4. Legacy toll tags versus switchable toll tags

Using legacy toll tags, SOVs and HOVs on I-70 East TEL's that are equipped with the hard case or sticker toll tags are charged the posted toll rate regardless of their occupancy status. If the toll tags are defective, the license plate tolling system will identify the account corresponding to the license plate and a transaction will be posted to the account. If an account is not found or if the account is not active, then the license plate tolling rate will apply and an invoice will be mailed to the vehicle's owner (see Figure 4.5).

Using the switchable toll tags, eligible carpools will not be charged a toll for using the TEL. These users must place the transponder switch into the "HOV" setting. If the user account is not active or doesn't exist, a license plate tolling rate will be applied. If the tag is defective and the user has an existing active account, the posted toll rate will be posted to the account regardless of the vehicle occupancy status.

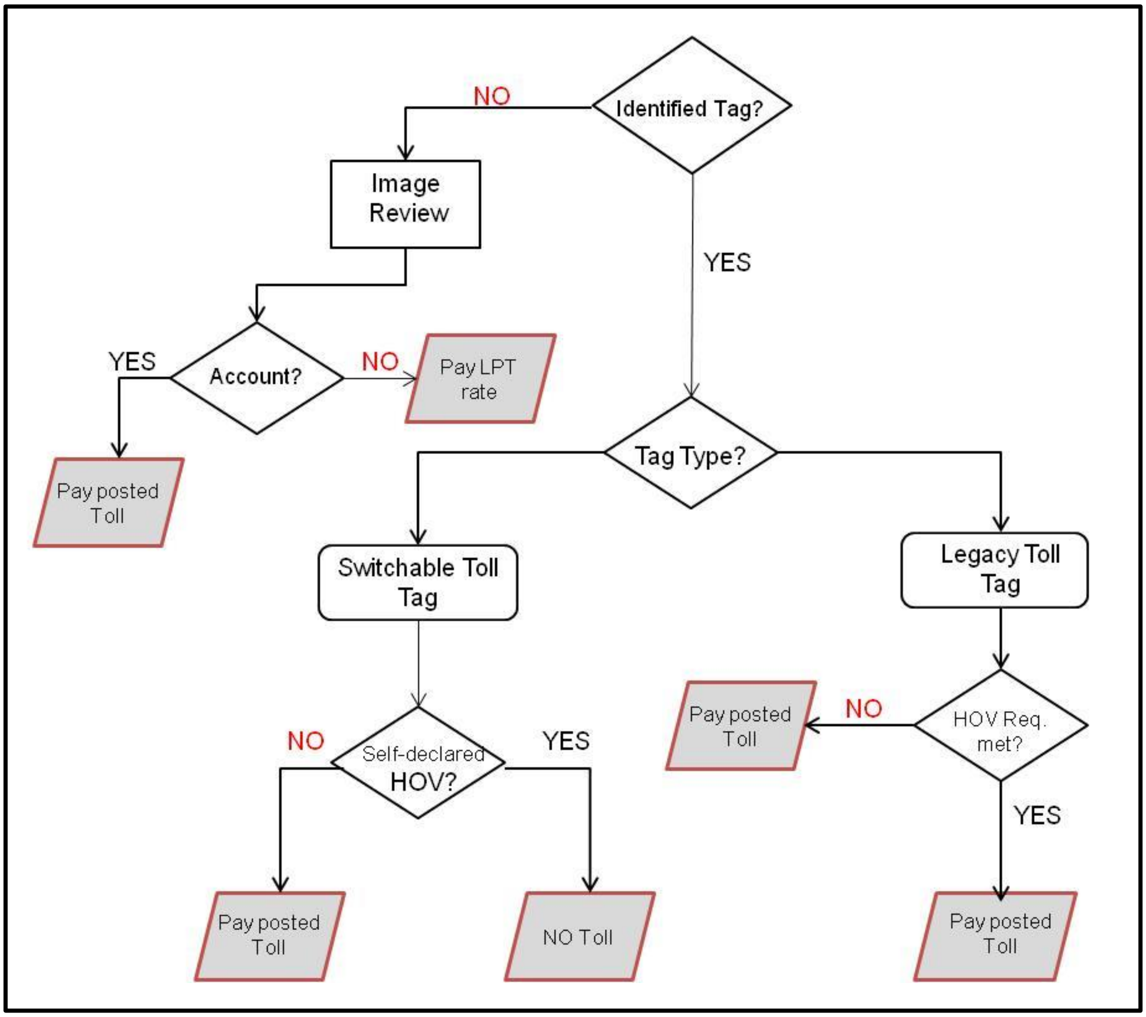


Figure 4.5: Legacy Toll Tag Versus Switchable Toll Tag

4.1.5. License plate tolling

License plate tolling—also known as video tolling—employs Automatic License Plate Recognition (ALPR) cameras and Optical Character Recognition (OCR) technology to identify a vehicle's license plate number. This technology is widely employed in Colorado (I-25, US 36, E-470, and the Northwest Parkway). License plate numbers are collected and names and addresses of drivers are requested from the State Department of Motor Vehicles. No occupancy status will be declared with LPT. Those drivers will be charged an LPT rate regardless of the vehicle occupancy status (see Figure 4.5).

4.2. Tolling Concept/Strategies

4.2.1. Ingress/egress locations and frequency

Access refers to the ability to enter and exit a TEL via an ingress or egress location. Access is a key design component of TEL's to safely and efficiently guide users in and out of the facility at desired locations. Access zones should be placed at logical points based on trip origins and destinations, traffic and revenue studies, geometric constraints, safety considerations, and operational impacts. The frequency of access zones should consider the travel demands of the area, the pricing strategy for the TEL, the length of the TEL, traffic operational impacts, and other factors. Ingress and egress locations are analyzed in conjunction with the tolling concept selected for the corridor (i.e., segment based, trip based, or zone based). Refer to Section 3 of this document for more information on the tolling concept.

Access management and regulation for the TEL is one of the fundamental tools for controlling traffic flow and safety in the general-purpose lanes and TEL lanes. There are **three broad categories** of access to TEL's (refer to Table 4.2 for pros and cons of each access type):

1. Grade separated, or direct access
2. At-grade access, or slip ramps
    a. Weave zone (combined ingress/egress)
    b. Weave lane (combined ingress/egress)
    c. Merge lane (individual ingress or egress)
3. Continuous access

Table 4.2: Pros and Cons of Different Access Strategies

STRATEGY	PROS	CONS
Grade separated	• Reduces weaving • Easier access across two facilities • Potentially lower tolling equipment capital cost	Higher construction cost and ROW
At-grade access		
Weave zone	Easily retrofitted on existing ROW	Creates weaving turbulence and needs additional mitigation strategies to maintain traffic safety and operations
Weave lane	Requires additional roadway width to create the weave lane	Creates weaving turbulence, lower than the weave zones, and requires weaving mitigation strategies
Merge lane	Smoother traffic operations, less weaving	Requires additional ROW
Continuous access	• Lower construction capital cost • Less impact to traffic operations than at-grade access strategies; has the same impact of an additional general-purpose lane	• High operational cost/enforcement cost • Potentially higher tolling equipment capital cost

4.2.2. Access analysis

The current I-70 East TEL's are planned to extend between I-25 and Chambers Road by adding one lane per direction to the existing I-70 footprint. Figures 4.6 and 4.7 depict the I-70 East origin volume distributions and their respective destination distributions along the length of the proposed TEL project in the eastbound and westbound directions for the AM and PM 2012 peak hours, respectively. Figures 4.6 and 4.7 are color-coordinated. For example, in the westbound direction, volumes originating from Peoria and farther east are shaded in yellow and total 6,683 vehicles. Their respective destinations (i.e., destination distribution) are shown in yellow below the zero-axis at each subsequent interchange. More detailed origin-destination data are provided in Appendix A and B.

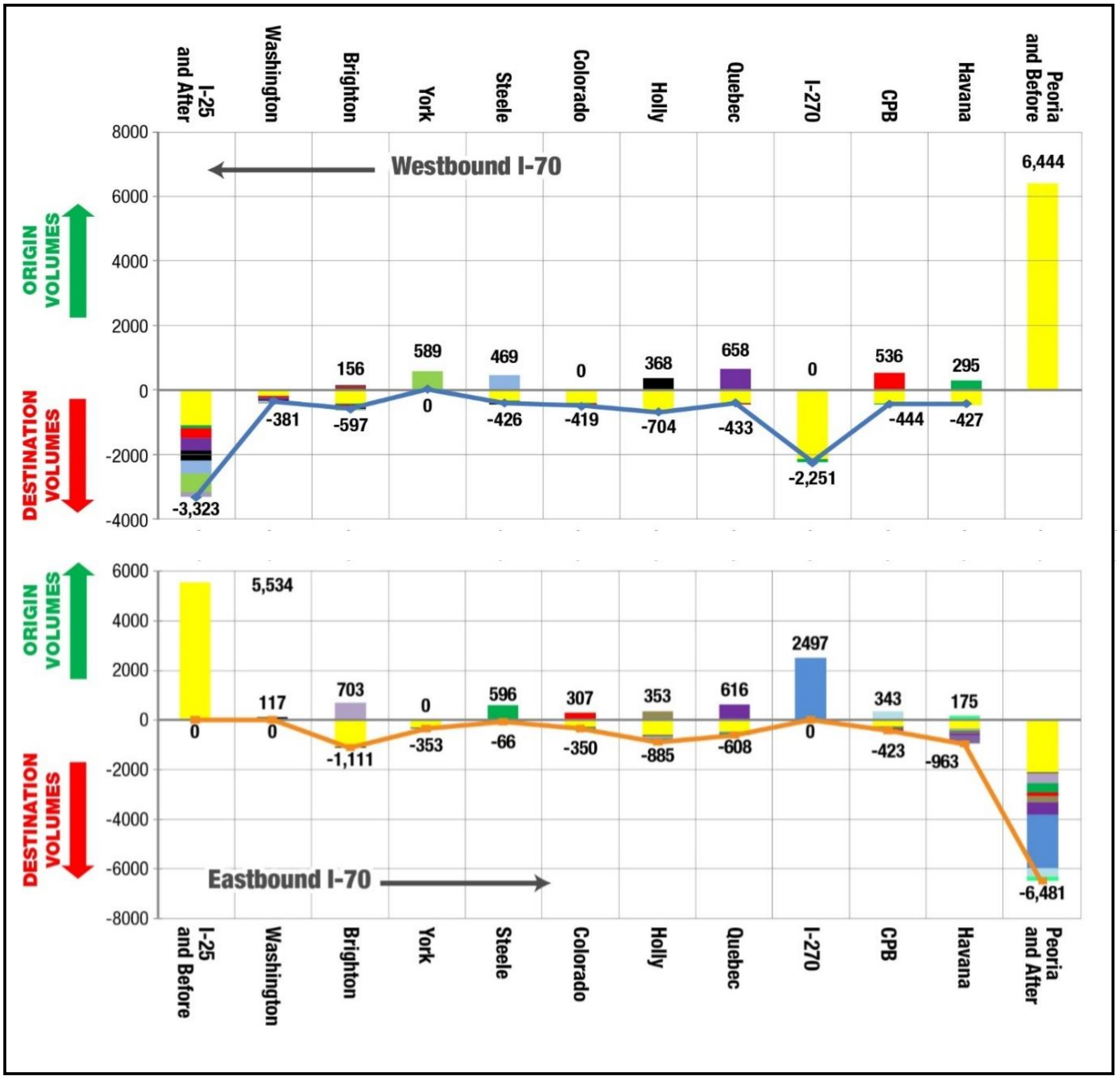


Figure 4.6: Eastbound and Westbound Origin-Destination Distribution (AM Peak, 2012)

In looking at the origin-destination volumes for 2012 in both the eastbound and westbound directions, I-25 and I-225 are major origins and destinations. Additionally, I-270 for westbound traffic and Pena Boulevard for eastbound traffic are other major origin-destinations. The critical nature of these major routes is important to note, with most of them being the major freeways within the metro Denver area. They provide the easiest routing between employment zones, shopping districts, and residential areas. In addition, Pena Boulevard provides direct access to Denver International Airport. Therefore, it is in the best interest of the I-70 East TEL's: (1) to encourage long trips to service major origins and destinations and to minimize short trips, (2) to maintain a safe travel environment for drivers, and (3) to provide smooth traffic operations. To achieve this goal, access to the TEL's must be regulated and restricted to a minimum.

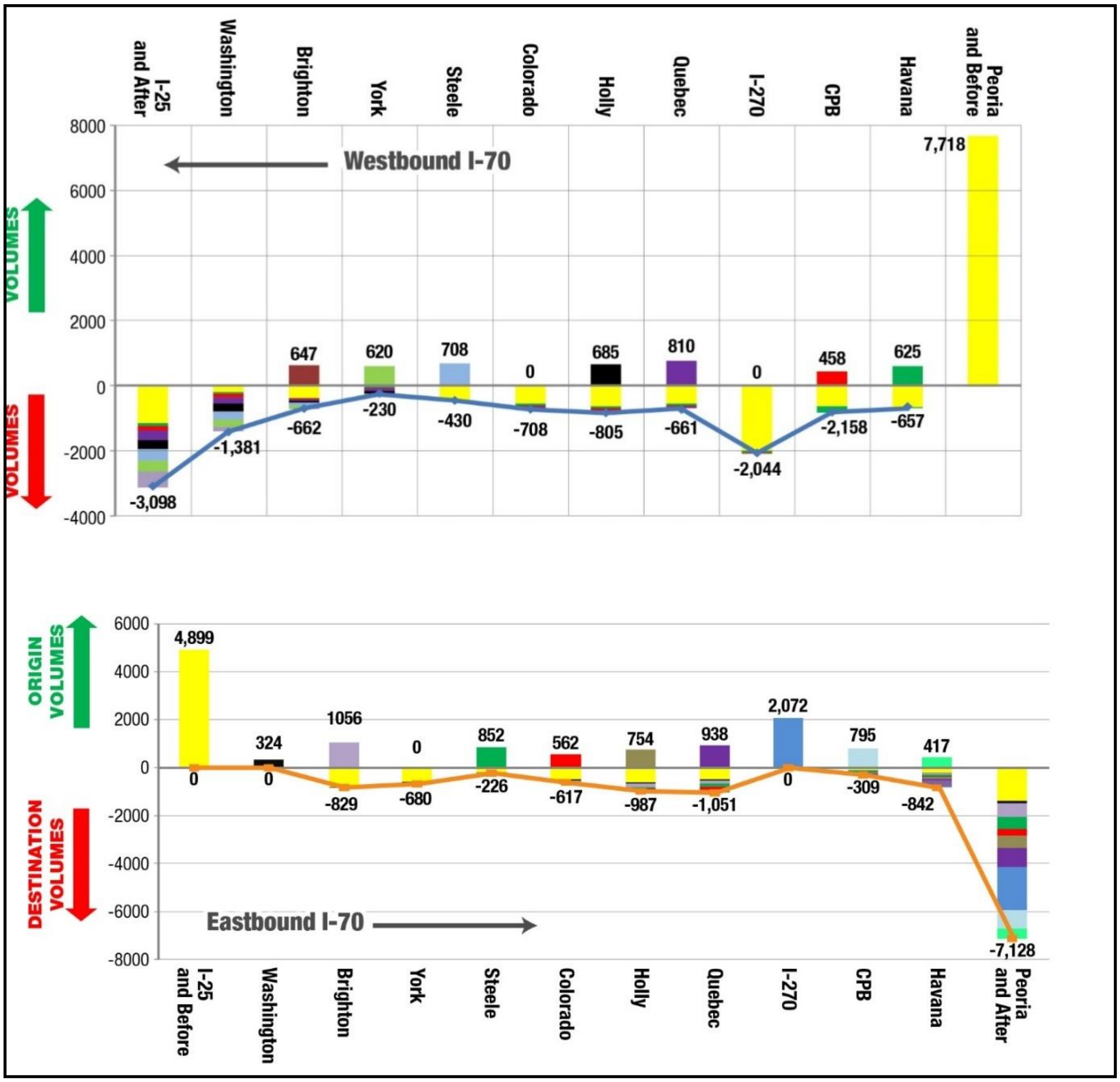


Figure 4.7: **Eastbound and Westbound Origin-Destination Distribution (PM Peak, 2012)**

Three locations for one combined ingress and egress zone were evaluated for the I-70 East TEL's:

- Colorado Boulevard
- Holly Street
- Quebec Street

Considering three criteria—including: (1) capacity utilization, (2) safety, (3) and operations—it is concluded that one access point in the eastbound and westbound direction should be located in the vicinity of Holly Street. Table 4.3 shows origin and destination volumes that can be accommodated by the three different access locations.

Table 4.3: Volumes Accommodated by I-70 East TEL

DIRECTION AND TIME OF DAY	ACCESS	VOLUMES ACCOMMODATED AT INITIAL INGRESS	VOLUMES ACCOMMODATED AT INTERMEDIATE ACCESS
EB AM Peak	Colorado Boulevard	3,679	594
	Holly Street	3,149	954
	Quebec Street	2,700	1,215
EB PM Peak	Colorado Boulevard	2,814	1,161
	Holly Street	2,198	1,426
	Quebec Street	1,694	1,963
WB AM Peak	Colorado Boulevard	2,377	1,092
	Holly Street	2,695	795
	Quebec Street	3,092	404
WB PM Peak	Colorado Boulevard	2,045	790
	Holly Street	2,475	520
	Quebec Street	3,002	213

4.2.3. Tolling strategies/concept options

Tolling strategies support business rules and define how the tolls are communicated to the public as they traverse the TEL. They also determine how tolls are calculated for a specific trip. Best practices around the country indicate that tolling concepts are highly dependent on the physical characteristics of the Tolled Express Lane corridor (i.e., length and number of access points). The following sections provide an overview for typical tolling strategies.

4.2.3.1. Trip based

The trip-based tolling strategy is a per-mile based tolling strategy that displays tolls for key destinations along the TEL. Upon entering the facility, the motorist is informed of the total trip toll for the displayed destinations. However, tolls for intermediate egress are not known to drivers. Drivers will only know that tolls for intermediate egress to key destinations are lower than posted tolls for the total trip. The advantage of the trip-based tolling strategy is that it encourages longer trips by "locking in" a toll rate for the entire trip. Another advantage of trip-based tolling is equity; drivers are charged per mile of travel. The disadvantage of the trip-based tolling strategy is that drivers would not know the exact toll for their trip in case they exit at an intermediate egress. Table 4.4 shows the advantages and disadvantages of the trip-based tolling strategy.

Examples: I-95 Express Phase (Florida); I-495 Express (Washington, D.C.); I-85 Express Lanes (Atlanta, Georgia); I-75 Express South and Northwest Corridor Express Lanes (under construction, Atlanta, Georgia)

4.2.3.2. Segment based

The segment-based tolling strategy is a per-mile based tolling strategy that divides the express lane into segments, where each segment starts with an ingress and ends with an egress. This tolling strategy displays one toll rate per sign; one toll rate before entering the facility for the immediate egress point and one toll rate for each intermediate egress thereafter. Therefore, drivers will know the toll rate for each segment they travel on and can add up individual segment toll rates to calculate their total trip cost. Toll rates on downstream segments are not "locked in" and may increase during the trip. The advantage of segment-based tolling is that it is equitable to drivers. The disadvantages of segment-based tolling are that drivers will have to calculate their trip cost and that toll rates for downstream segments may increase during the trip, which does not encourage long trips. Table 4.4 shows the advantages and disadvantages of the segment-based tolling strategy.

Examples: US 36 (Colorado, opened in 2015); I-4 Express Lanes (under construction, Orlando, Florida)

4.2.3.3. Zone based

The zone-based tolling strategy divides the express lane corridor into zones. Zone boundaries are established based on major destinations (high-volume destinations). Tolls are displayed for each zone and drivers are charged a toll rate per zone regardless of where they enter or exit the zone. Consequently, drivers who drive a portion of a zone are charged the same amount as drivers who drive the entire length of the same zone. This creates inequities among drivers. Each toll sign may have two or three lines displaying the rates for subsequent zones. Tolls for (subsequent) zones may be "locked in" after drivers enter the express lanes; therefore, this strategy encourages long trips. The advantage of zone-based tolling is that it encourages long trips and discourages short trips. The disadvantage is the pricing inequity in cost per mile among drivers.

Examples: I-15 (Utah); I-15 (San Diego), BAIFA Express Lane Network; I-394 and I-35w (Minneapolis)

Table 4.4: General Pros and Cons of Tolling Concepts

TOLLING CONCEPT	PROS	CONS
Trip based	• Drivers know full range of toll options (shortest and longest trip are fixed at point of entry) • Promotes longer trips if toll rates are locked in; thus, less interaction/friction at downstream weave zones	• Drivers not informed of intermediate trip toll rates (example: heavy congestion near the end of the TEL will increase longer trip toll rates and may deter intermediate trip users from entering, even though their trip is largely congestion free)

TOLLING CONCEPT	PROS	CONS
	• Allows for toll rate signs to display toll rates to major destinations far downstream • Viewed as an equitable tolling concept • Accommodates future expansion of TEL if major destinations (end trips) are not changed	• If congestion changes after entry, pricing will not reflect current conditions • The longer the facility is, the more difficult it is to provide entry prices that reflect actual traffic conditions that will be experienced downstream
Segment based	• Does not matter how long the facility is • Maximizes TEL utilization on a per-segment basis by charging for current traffic conditions rather than by entire trip or zone conditions • Viewed as an equitable tolling concept • Easily accommodates future growth of TEL network	• Drivers do not know full price of trip when entering TEL • Drivers are required to make TEL travel decision at every segment; may discourage longer trips and increase weaving between GP and TEL • Toll rates for downstream segments may increase during the trip, which does not encourage long trips and may increase weaving between GP and TEL
Zone based	• Provides better means of managing lane usage by charging for current traffic conditions • Encourages long trips and discourages short trips; may lead to a decreased weaving between GP and TEL • Allows for flexibility in signing plan; can sign for next zone and total zones making up longest trip or can sign for just current zone • Does not require tolling point for every entry and exit; thus, lower capital cost	• Inequitable tolling concept • If congestion changes after entry, pricing will not reflect current conditions • The longer the facility is, the more difficult it is to provide entry prices that reflect actual traffic conditions that will be experienced downstream

4.2.4. Recommendation

In looking at the origin-destination volumes for 2012, peak AM and PM hours, in both the eastbound and westbound directions, I-25 and I-225 are major origins and destinations. Therefore, it is in the best interest of the I-70 East TEL's to encourage long trips to service major origins and destinations and to minimize short trips to maintain a safe travel environment for drivers and smooth traffic operations. To achieve this goal, access to the TEL's must be regulated and restricted to a minimum (see Figure 4.8). Therefore, one combined ingress/egress access zone is recommended in the vicinity of Holly Street. It is also recommended to have one tolling zone eastbound and one tolling zone westbound.

Figure 4.8: Eastbound and Westbound Ingress/Egress

4.3. Pricing

The primary focus of express lanes implementation across the country is to use the appropriate pricing strategy to maximize throughput and maintain a pre-specified LOS in express lanes while considering revenue optimization. Time of Day (TOD) and dynamic tolling are the two prevalent pricing strategies for TEL's. TOD pricing is set to a fixed price schedule, typically each hour of the day. As for Dynamic pricing, tolls change intermittently (5 to 15 minutes) with varying traffic conditions. Table 4.5 presents high-level pros and cons for dynamic and TOD tolling.

Table 4.5: Pros and Cons of Dynamic and TOD Tolling

TOLLING STRATEGY	PROS	CONS
TOD tolling	• Simple to implement compared to dynamic tolling • Pricing is based on historical data, and is easy to convey to driver. • Drivers are aware of the toll rates prior to arriving to the TEL (except override situations)	• Does not allow for toll rates changes in real-time in case of non-recurring congestion • Does not manage traffic demand in the TEL in abnormal situations.
Dynamic tolling	• Allows for changing toll rates in real-time with demand fluctuation. • Provides better traffic demand management	• Requires constant monitoring of toll rates • Requires intervention at the beginning to stabilize the dynamic pricing algorithm • Require additional efforts and cost compared to TOD pricing

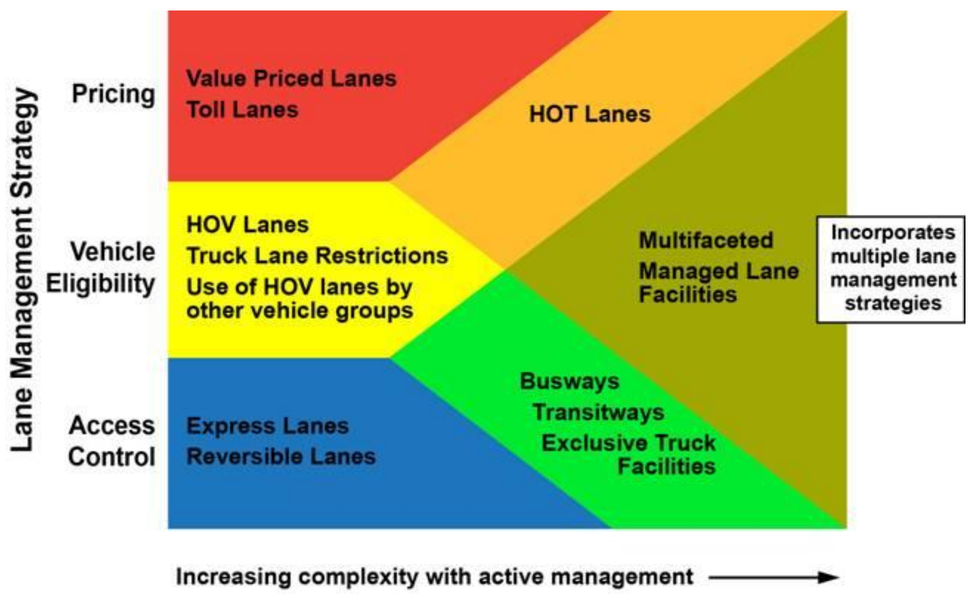
4.3.1. Recommendation

Dynamic pricing, compared to TOD pricing, is more robust in managing demand and ensuring reliable trips in an unpredictable environment such as crashes and other types of incidents. Therefore, it is recommended that dynamic pricing be implemented on I-70 East TEL's.

5. Active Traffic Management

5.1. Active Traffic Management Strategies

This section addresses the potential role of ATM within the I-70 East TEL's corridor. Figure 5.1 shows different applications of express lanes and their increasing complexity with ATM. Single operational strategy express lanes are depicted on the left side of the figure and include pricing (including value-priced lanes and toll lanes), vehicle eligibility, and access control (including express lanes and reversible lanes). Express lanes comprising more than one operational strategy are illustrated in the middle of the figure and include HOT lanes that combine pricing and vehicle eligibility with busways, transitways, and exclusive truck facilities that combine vehicle eligibility and access control. The right side of the graphic shows express lanes with multiple lane management strategies.



(Source: http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/revision/jan2011/mgdlaneschp8/sec8.htm)

Figure 5.1: ATM in Express Lanes Examples

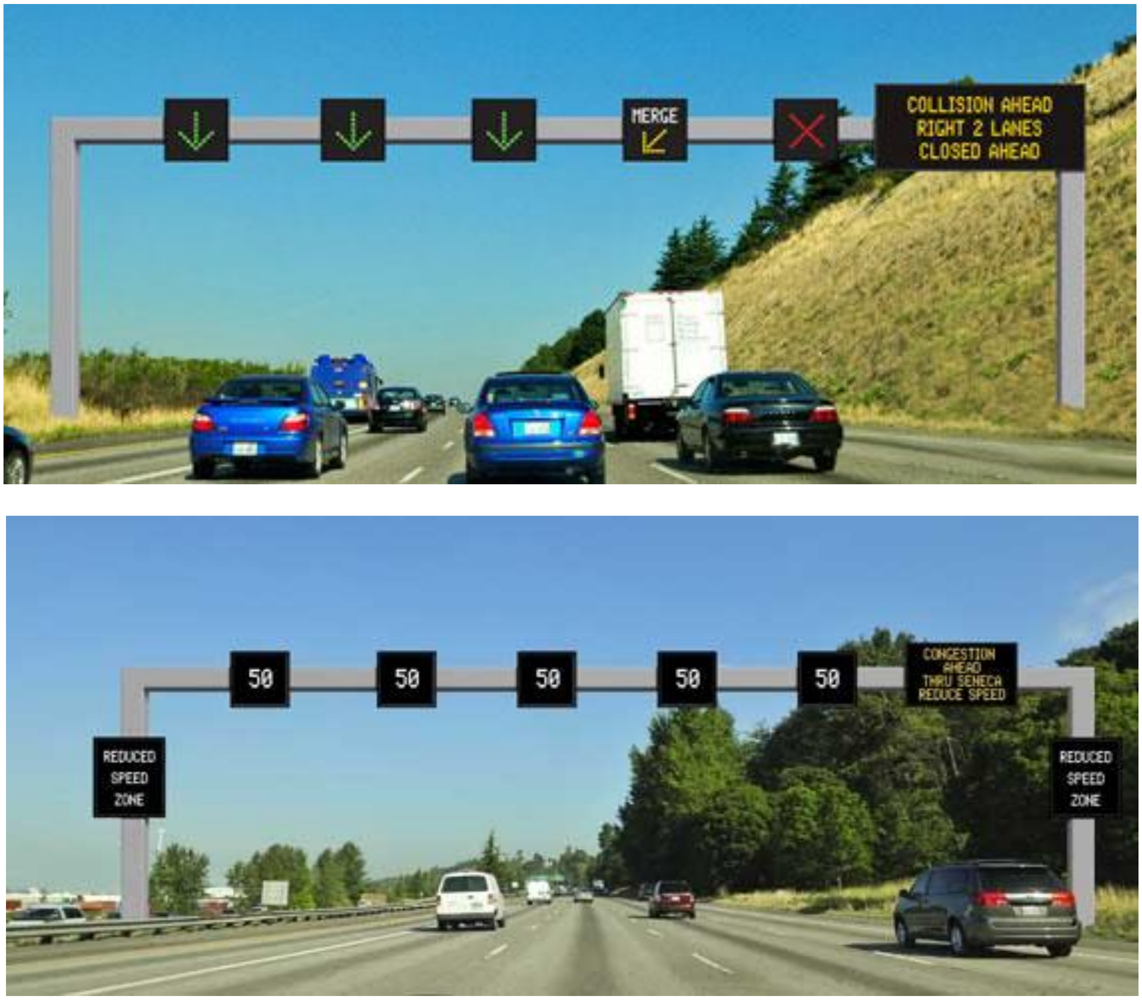
ATM is a system that dynamically manages and controls traffic based on conditions in real time to improve traffic flow and safety. ATM strategies offer a variety of potential benefits, including:

- Increased throughput
- Increased capacity
- Decreased number of primary incidents
- Decreased number of secondary incidents
- Uniform speeds (speed harmonization)
- Decreased headways
- Uniform driver behavior
- Increased trip reliability
- Delayed onset of freeway breakdown
- Reduced traffic noise
- Reduced emissions
- Reduced fuel consumption

Table 5.1. Potential Benefits of ATM Strategies

ATM Strategy	Increased throughput	Increased capacity	Decrease in primary incidents	Decrease in secondary incidents	Decrease in incident severity	More uniform speeds	Decreased headways	More uniform driver behavior	Increased trip reliability	Delay onset of freeway breakdown	Reduction in traffic noise	Reduction in emissions	Reduction in fuel consumption
Speed harmonization	X		X		X	X	X	X	X	X	X	X	X
Temporary shoulder use	X	X							X	X			
Queue warning			X	X	X	X	X	X	X		X	X	X
Dynamic merge control	X	X	X			X		X	X	X	X	X	X
Construction site management	X	X							X		X	X	X
Dynamic truck restrictions	X	X				X		X	X			X	X
Dynamic rerouting and traveler information	X		X	X				X	X			X	X
Dynamic lane markings	X	X							X				
Automated speed enforcement			X		X	X		X	X			X	X

(Source: *Active Traffic Management: The Next Step in Congestion Management*, report number FHWA-PL-07-012)



Source: http://www.wsdot.wa.gov/Operations/Traffic/ActiveTrafficManagement/ATMHowTheSymbolsWork.htm

Figure 5.4: How ATM Works in Washington State

5.2. Future Conditions and Proposed ATM Strategies

The I-70 East project is expected to bring much-needed capacity improvement to one of the most congested corridors in the state of Colorado. Major interchange redesigns and additional capacity in the form of added travel lanes, auxiliary lanes, and TEL's will certainly improve the overall LOS for this 12-mile section.

ITS, in conjunction with congestion-priced TEL's, will further enhance traffic operation and safety of the facility by maximizing throughput capacity. Inclusion of ATM strategies are an integral and supplementary component of a comprehensive ITS system that can result in a reduction in collisions and their negative effects not only on traffic flow and overall freeway capacity, but also in number and severity of injuries and property damage to the roadway users.

In assessing the applicability of ATM strategies for the I-70 East project, a cursory evaluation of LOS for both the opening year of 2021 and the design year of 2035 was performed. The primary purpose of the LOS analysis was to identify freeway segments that may be susceptible to operational failure in case of a traffic incident. Traffic incidents such as crashes, stalled cars, and debris in the roadway block travel lanes, reducing the roadway's capacity. Even when lanes are not physically blocked, activities on the shoulder (e.g., police action) or in the opposite direction of travel (e.g., crash scene being cleared) can lead to changes in driver behavior that result in congestion and/or secondary collisions The LOS analyses for the basic freeway segments within the project limit of I-70 East were performed for every hour of operations, both westbound and eastbound.

Results for the analyses of year 2021 revealed that all the segments are expected to operate at an acceptable level of LOS D or better. The segments from Washington Street to Brighton Boulevard and Steele Street/Vasquez Boulevard to Colorado Boulevard are shown to operate in the upper limit of the LOS D during both AM and PM peak periods in both eastbound and westbound directions. These segments are highly susceptible to congestion and LOS failure during a traffic incident.

Another parameter in assessing the future operations of I-70 East is the average operating speed. As depicted in Figure 5.5, below, the average travel speed in the eastbound direction for the opening year of 2021 is anticipated to fall to 25 mph to 30 mph during the morning peak hours from Colorado Boulevard to I-270. The afternoon peak period average travel speed of 20 mph can be expected from Colorado Boulevard to I-270 and again from Peoria Street to I-225.

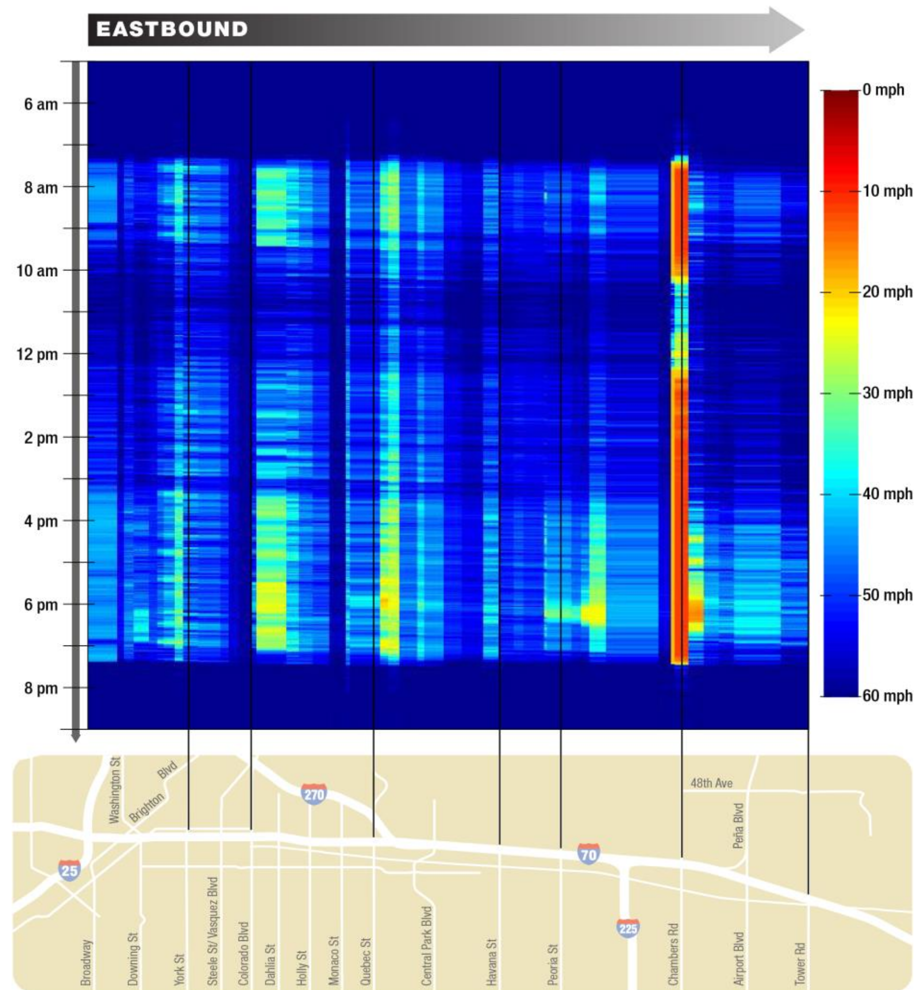


Figure 5.5: Eastbound Speed Heat Diagram Map, Opening Year 2021

Figure 5.6, below, depicts the average travel speed for the westbound lanes of I-70 East for the opening year of 2021. The average travel speed during the morning peak period for Steele Street/Vasquez Boulevard to I-25 is expected to fall below 30 mph. During the afternoon peak period, average travel speed for the same segments decreases to the 10 mph to 25 mph range.

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Figure 5.6: Westbound Speed Heat Diagram Map, Opening Year 2021

The average travel speeds for the design year of 2035 in the eastbound direction (assuming only Phase 1 improvements are made to I-70) are depicted in Figure 5.7. During morning peak period, segments between Colorado Boulevard and Holly Street, I-270 and Central Park Boulevard, and Peoria Street and I-225 are expected to operate at or below 25 mph. An afternoon peak period average travel speed of 25 mph can be expected for Washington Street to York Street and Colorado Boulevard to Holly Street. Eastbound travelers from Monaco Street to past the I-270 merge and from Peoria Street to the I-225 diverge can expect average travel speeds of 15 mph.

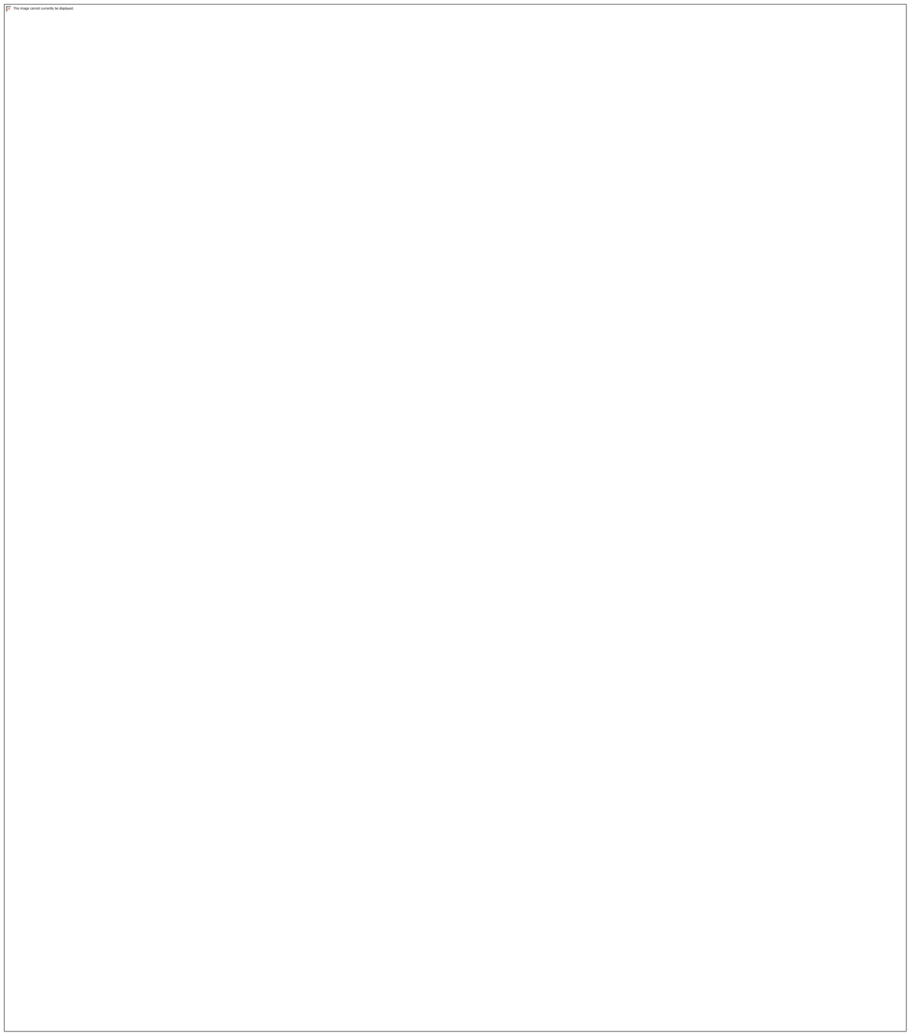

Figure 5.7: Eastbound Speed Heat Diagram Map, Design Year 2035

Westbound, an average travel speed of 10 mph can be expected for the afternoon peak period of design year 2035 for Peoria Street to Central Park Boulevard, Quebec Street to Holly Street, and Steele Street/Vasquez Boulevard to I-25, as depicted in Figure 5.8 (assuming only Phase 1 improvements are made to I-70).

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Figure 5.8: Westbound Speed Heat Diagram Map, Design Year 2035

Results of the LOS analyses and the examination of average travel speeds both confirm susceptibility of the corridor to traffic incidents that may greatly degrade the operations and throughput capacity of the system.

As mentioned earlier, inclusion of ATM as a supplementary sub-system to the planned ITS and Electronic Toll Collection (ETC) infrastructure for the I-70 East project not only enhances the regular traffic operations in the form of increased travel speed and maximum throughput, but it also minimizes the occurrence of primary and secondary incidents.

ATM sub-systems, including lane use systems (LUS), queue warning, and speed harmonization—through utilization of Lane Use Signs, Overhead Variable Message Signs (OHVMS), and/or Side-Mounted Variable Message Signs (SMVMS)—are expected to reduce the number and severity of collisions and their negative effects.

5.3. Recommendations

Results of the aforementioned safety, average travel speed, and LOS analyses indicated that the corridor is anticipated to operate at an acceptable level of service (LOS D or better). However, there are extended periods during which many roadway segments are highly susceptible to a very low operating speed and relatively high traffic density. If a traffic incident occurs, it will destabilize the traffic flow and may result in secondary accidents. Variation in operating speed (due to major ramp junctions, weave areas, and close interchange spacing) can further degrade the traffic flow, not only creating an unsafe condition, but also decreasing throughput capacity. The following sections describe why the proposed ATM sub-systems/strategies merit favorable consideration.

5.3.1. Regional consistency

Major corridors currently in planning, design, and construction phases in the Denver area are implementing ATM strategies as an integral component of their ITS systems. US 36 and I-25 are using ATM strategies/sub-systems to bring added safety, operational improvement, and traffic management for the users of those facilities. The traveling public in the Denver area uses many of these major corridors in its daily commute. Consistency in design and operations—such as application of roadway design standards, traffic control devices, and traffic information systems—brings uniformity and helps meet driver expectations.

5.3.2. Minimal capital and operation costs

The I-70 East project is anticipated to include the entire necessary infrastructure to support a robust congestion pricing and electronic toll collection system. This infrastructure includes, but is not limited to, fiber optic back bone, power supply, Traffic Management Center, sensors, CCTV, VMS, controller cabinet, WMS, AVI, cameras, etc. Addition of the proposed ATM sub-systems to the already planned tolling and ITS infrastructure will have a minimal impact to the overall project capital and annual operation costs. Various software applications in support of toll collection, toll setting, speed monitoring, incident detection/ verification, information dissemination, and traffic management are anticipated to be included.

5.3.3. Anticipated benefits

ATM sub-systems/strategies aim to maximize the effectiveness and efficiency of a roadway and result in improved safety, trip reliability, and throughput. A report summarizing the result of a scan by the FHWA and the American Association of State Highway and Transportation Officials (AASHTO)—as presented in *Planning for Active Traffic Management* in Virginia by Michael Fontaine and John Miller—concluded that, "The scan found significant, broad benefits of using ATM, including the following: Increases in throughput of 3% to 7% during congested periods, decreases in primary incidents of 3% to 30% and decreases in secondary incidents of 40% to 50%, increased trip reliability, and improved ability to delay the onset of breakdown conditions."

A 2014 U.S. Department of Transportation report by the ITS Joint Program Office documents the results of several before-and-after studies as related to the application of ATM sub-systems/strategies. The following is a brief summary of the results:

- Collisions on Interstate 5 (I-5) in the Seattle area have been reduced by 65 percent to 77 percent in a 7.5-mile corridor where an active traffic management system was deployed.

- Intelligent speed control applications that smooth traffic flow during congested conditions can reduce fuel consumptions by 10 percent to 20 percent without drastically affecting overall travel times.

- Field data collected over the past two decades show variable speed limit (VSL) systems can reduce crash potential by 8 percent to 30 percent.

- A variable speed limit system on the I-270/I-255) loop around St. Louis reduced the crash rates by 4.5 percent to 8 percent due to more homogenous traffic speed in congested areas and slower speed upstream.

Figure 5.9, below, shows the locations of proposed ATM/tolling mechanisms for the I-70 East project area.

Figure 5.9: ATM/Tolling Locations

6. Design

6.1. Separation

The MUTCD identifies three types of separation treatment for express lanes: (1) buffer-separated, (2) barrier-separated, and (3) contiguous. Each treatment is described as follows, and depicted in Figure 6.1 below:

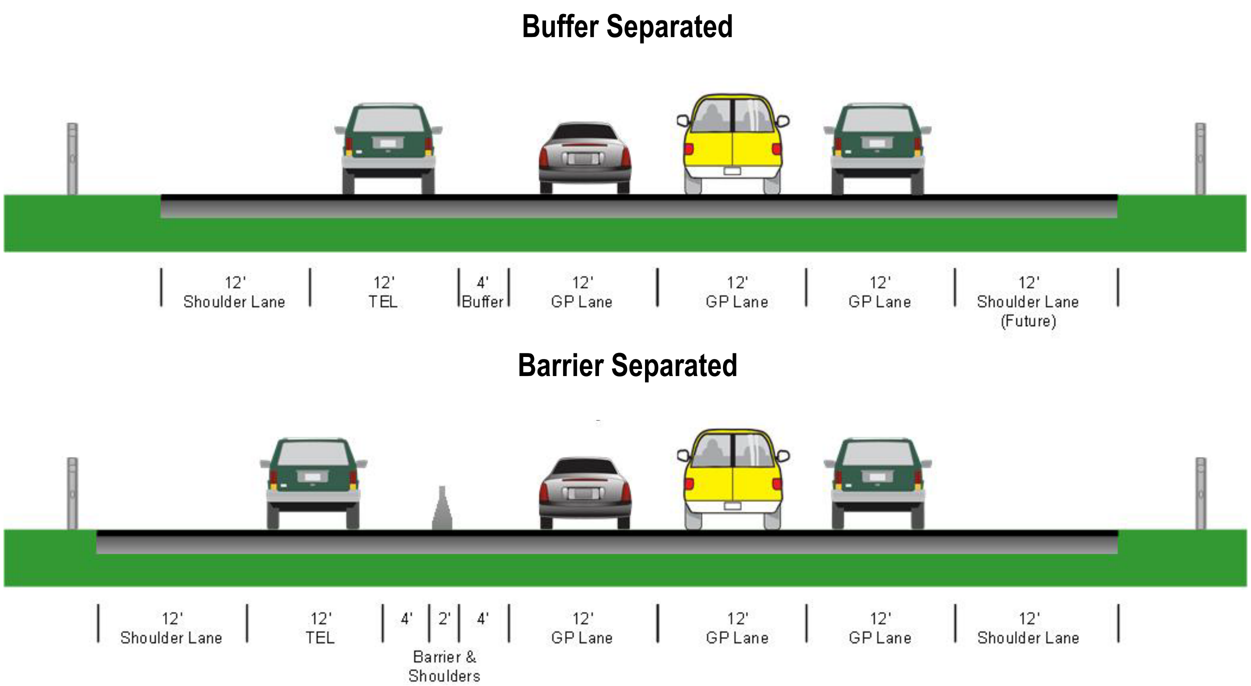


Figure 6.1: Separation Treatment

Barrier-separated facilities use a physical barrier such as a concrete barrier or pylons to separate the tolled lanes from the general-purpose lanes. There are three main types of barrier separation techniques:

1. Concrete barrier separation;
2. Grade separation;
3. Longitudinal pavement markings with delineators.

The I-25 Reversible Express Lanes segment north of Downtown Denver and on US 36 between I-25 and Pecos Street are examples of barrier-separated facilities.

Buffer-separated facilities use pavement markings and a buffer space, as opposed to a physical barrier, to delineate between the Tolled Express and GP lanes. This is the most common type of separation. The width of the buffer space can vary depending on the available pavement and right of way. For example, the US 36 Express Lane will consist of a four-foot striped buffer while the North I-25 Express Lane from US 36 to 120th Avenue will provide a two-foot striped buffer.

A contiguous condition exists when the express lane is directly adjacent to the GP lanes with only the width of the pavement markings separating the express lane.

I-70 East is envisioned to have a buffer-separated TEL. Table 6.1, below, describes the pros and cons of the different separation strategies.

Table 6.1: Pros and Cons of Different Separation Strategies

ITEM	PROS	CONS
Barrier separation		
Grade separation	• Perceived as a safer option compared to buffer separation • Incidents in GP lanes do not affect the TEL • Lower toll violation compared to buffer separation emanating from access at illegal location	• High capital cost /ROW • Very limited emergency response access • Longer implementation
Concrete Barrier Separation	• Lower toll violation compared to buffer separation emanating from access at illegal location • Perceived as a safer option compared to buffer separation • Lowest maintenance cost compared to other barrier separation methods	• High capital cost compared to buffer separation and delineators • Limited emergency response access • Wider corridor/ROW required
Delineators	• Easier access for emergency responders • Easier for expansion and modification • Lower capital cost	• High delineators maintenance cost • Higher illegal entry violation compared to grade and concrete barrier separation
Buffer Separation		
	• Lowest capital and maintenance cost • Easier access for emergency/ incident responders • Easy future modifications and expansions	• Highest toll violation rate • Potential safety and operational issues resulting from the proximity to GP lanes • High cost of enforcement

6.2. Access

Access refers to the ability to enter (ingress) and exit (egress) an express lane. Access is a key design component of express lanes, safely and efficiently guiding users in and out of the facility at desired locations. Access zones should be placed at logical points based on trip origins and destinations, Traffic and Revenue studies, geometric constraints and safety considerations. The frequency of access zones should consider the travel demands of the area, pricing strategy for the express lane, length of express lanes, and other factors.

Access types may consist of ingress only, egress only, or combined ingress and egress. There can be a mixture of access types within a given facility as desired. As a general guideline, a minimum weave distance of 800 feet per lane should be given from the on-ramp to the start of an access zone, or from the end of the access zone to the next off-ramp. The FHWA recommends 600 feet to 800 feet per lane, while California recommends a minimum of 800 feet. A distance of 750 feet to 800 feet per lane generally has been used on recent CDOT projects. Recent published guidelines of express lanes show a trend toward longer access zones and longer weave areas. Access zones should be 1,000 feet long at a minimum and preferably 2,000 feet or longer, using a white broken eight-inch stripe as a divider to encourage ingress and egress to the TEL. The state of California is transitioning to a minimum 2,000-foot opening due to recent safety studies.

The access zone lengths mentioned above are minimum guidelines. Access zones can vary in length and be much longer depending upon the interchange density, roadway geometry, and desired operational scheme. For example, an access zone of 2,500 feet or more may be used to spread out the weaving of vehicles and alleviate an otherwise concentrated access point. Some facilities have continuous access zones in which vehicles may enter and exit the express lanes at any point.

The design speed for this section of I-70 East is 60 mph from I-25 to Colorado Boulevard and 70 mph east of Colorado Boulevard. Interchanges generally are spaced further apart than in more urban areas. Therefore, it is recommended to use longer minimum weave distances, where possible. These minimums have been found to provide adequate distance for vehicles entering and exiting the facility to safely maneuver to the Tolled Express Lane Access Zones. However, these are “minimums” and longer distances may be desirable if they can be accommodated.

Access management and regulation for the TEL is one of the fundamental tools to managed traffic flow and safety in the GP and TEL lanes. There are three broad categories:

1. Grade-separated or direct access;
2. At-grade access or slip ramps;
    a. Weave zone (combined ingress/egress)
    b. Weave lane (combined ingress/egress)
    c. Merge lane (individual ingress or egress)
3. Continuous access

I-70 East TEL is envisioned to have an at-grade access with weave zones (see Figure 6.2). Table 6.2, below, describes the pros and cons of the various access strategies.

Table 6.2: Pros and Cons of Different Access Strategies

ITEM	PROS	CONS
Grade-separated access		
	• Reduces weaving • Easier access across two facilities	Higher construction cost and ROW
At-grade access		
Weave zone	Easily retrofitted on existing ROW	Creates weaving turbulence and needs additional mitigation strategies to maintain traffic safety and operations
Weave lane	Requires new roadway width to create the weave lane	Creates weaving turbulence, lower than the weave zones, and requires weaving mitigation strategies
Merge lane	Smoother traffic operations, less weaving	Additional ROW
Continuous access		
	Lower capital cost	High operational cost/enforcement cost

6.2.1. Recommendation

Phase I, i.e., the project, is envisioned to have a weave lane as depicted in alternative 2 of Figure 6.2.

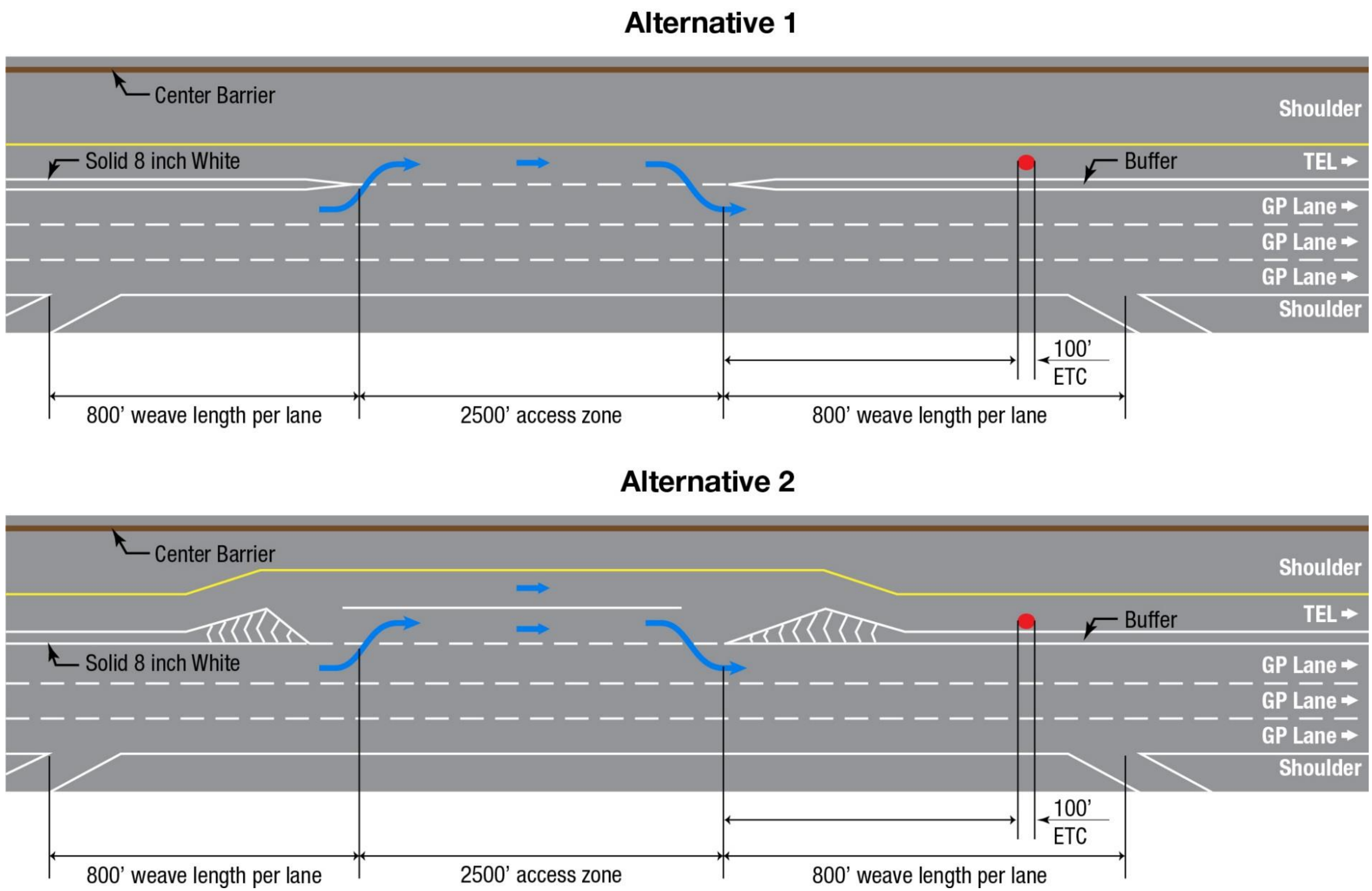


Figure 6.2: Access Zone Alternatives for I-70 East

6.3. Signing and Marking

6.3.1. Variable Tolling Message Sign

The Variable Tolling Message Sign (VTMS) will be a combination of a static sign with an electronic VMS insert that will be utilized to display the specific tolls for each segment of the corridor. These will be positioned overhead between the express lane and the left-most general-purpose lane to inform both the express lane users as well as the general-purpose lane users who may wish to enter or exit the express lane at the next access zone. Figure 6.3 shows conceptual layouts of VTMS signs. As shown, the toll information for the next two toll segments will be displayed. The VTMS will be located upstream of the express lane access zone to allow the roadway users sufficient time to make decisions.

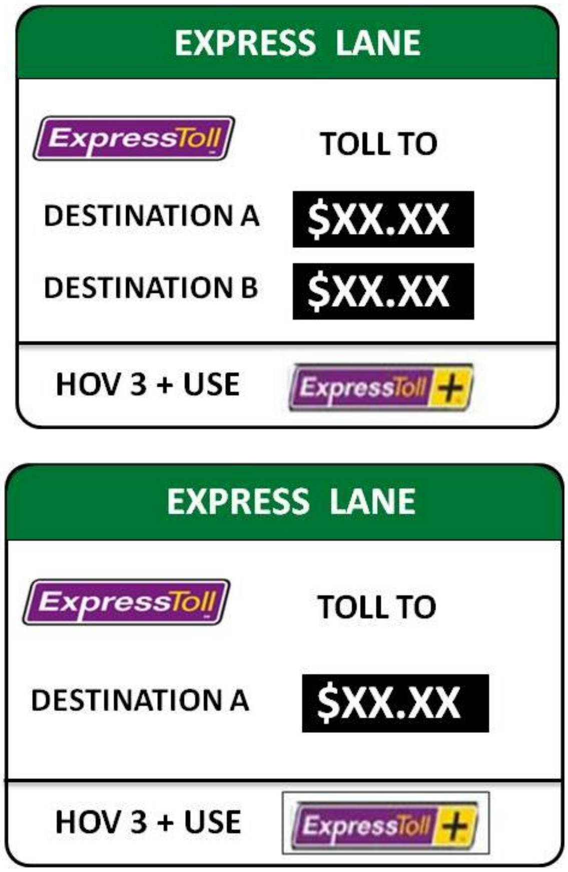


Figure 6.3: Sample VTMS Signs (Not to Scale)

Figure 6.4, below, shows locations of the proposed VTMS signs.

Figure 6.4: Proposed Signing Locations

6.3.2. Signing and Striping

The signing and striping associated with the tolling operations will be a critical component of the tolling system. Sufficient signage will be needed to provide enough advance warning to drivers of the location of the access zone so that they are easily able to enter and exit the express lane. In addition, clear signing and striping will reduce confusion for drivers and minimize lane buffer violations in which drivers enter and exit the express lane at locations outside of the designated ingress/egress points. Figure 6.5 shows a variety of signs typically used on TEL facilities.

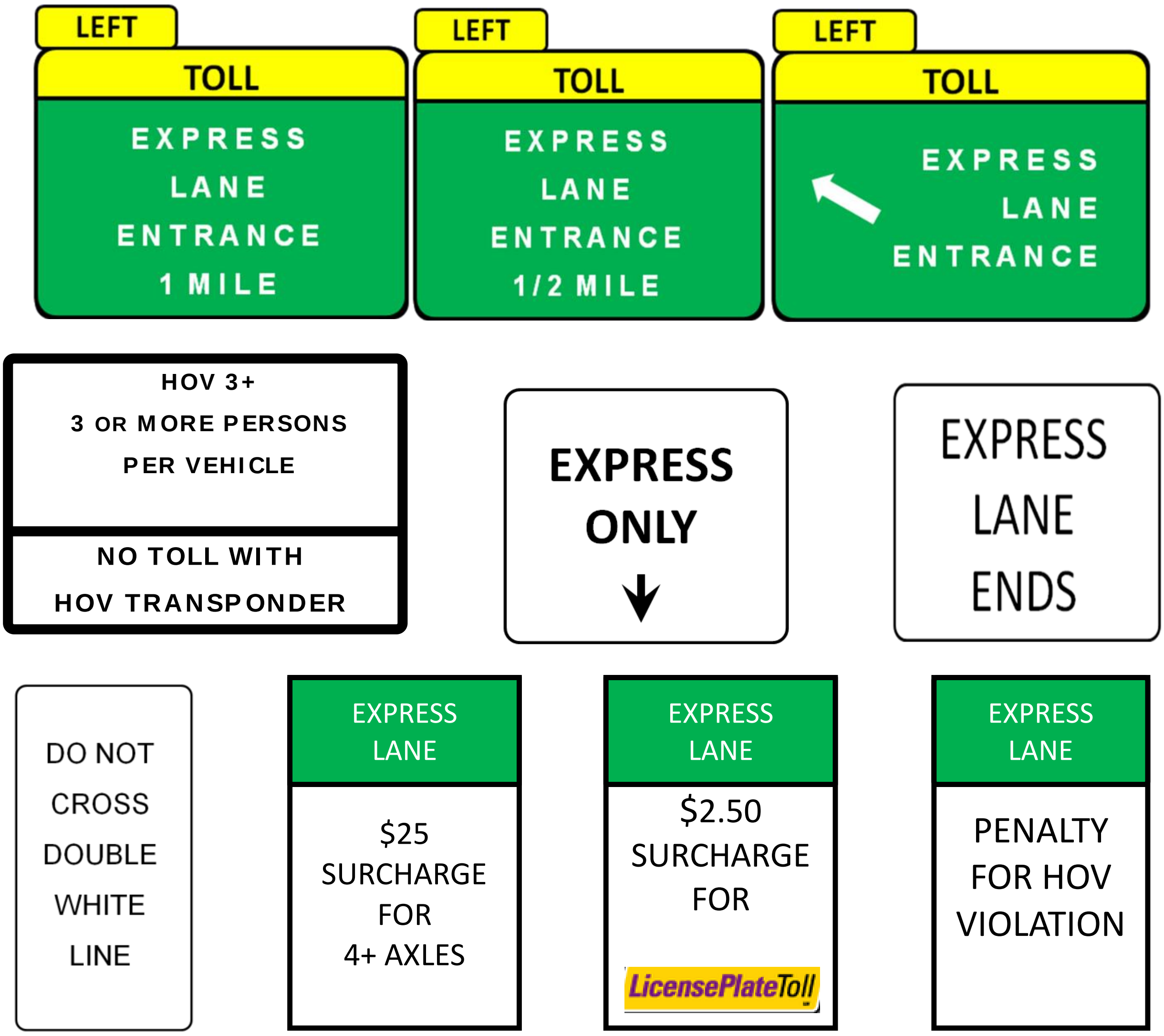


Figure 6.5: Typical TEL Signage

7. Preliminary Requirements and Procedures

7.1. Express Lanes Policies

7.1.1. Hours of operation

I-70 East TEL's will operate 24 hours a day, 7 days a week, and 365 days a year in both directions. During the hours of operations, only eligible vehicles are allowed access to the TEL. The following section describes details about vehicle eligibility.

7.1.2. Vehicle Eligibility

Federal law (23 USC 129 and 23 USC 166, as modified under MAP-21) allows for the consideration of transit, paratransit, motorcycles, toll-paying single-occupant vehicles, and designated hybrids on HOV lanes operated on roadways constructed with federal funds. As of October 2013, based on a study[1] by FHWA, 13 states (shown in Figure 7.1) had some legislation allowing some combination of low-emission and energy-efficient, plug-in electric or hybrid gasoline-powered vehicles to access HOV and HOT lanes without meeting the minimum occupancy requirements. These states include Arizona, California, Colorado, Florida, Georgia, Hawaii, Maryland, New Jersey, New York, North Carolina, Tennessee, Utah, and Virginia.

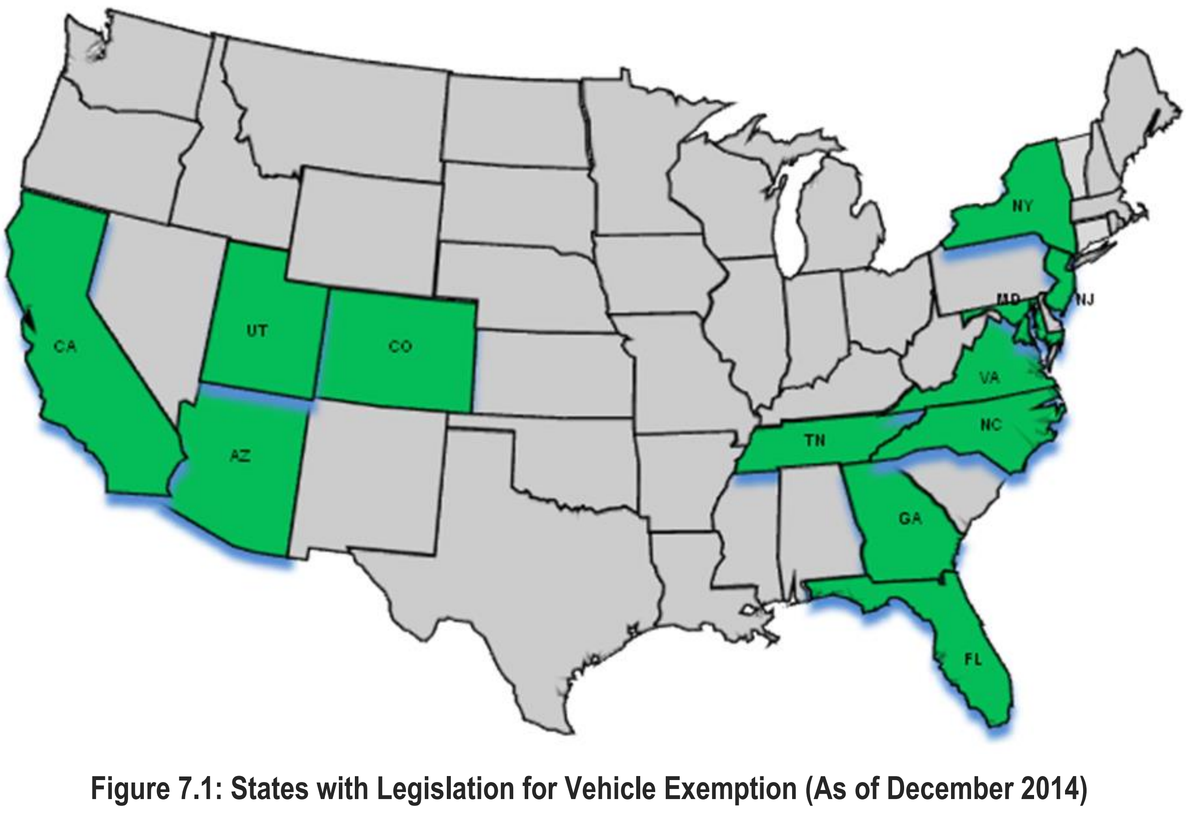


Figure 7.1: States with Legislation for Vehicle Exemption (As of December 2014)

Agencies are required to establish, manage, and support performance monitoring, evaluation, and reporting programs for the HOV/HOT facilities. The exempt vehicles' impact on the HOV facility and adjacent highways must be continuously monitored and reported on an annual basis. The agencies also must establish, manage, and support enforcement programs to ensure the HOV/HOT facility is operated in accordance with the requirements and that agencies limit or discontinue use of the HOV/HOT lanes by these types of vehicles whenever operations are degraded.

[1] *Impact of Exempt Vehicles on Express Lanes*; Publication No. FHWA-HOP-14-006; January 15, 2014

In 2008, the Colorado Department of Transportation commenced the hybrid vehicle program and allowed owners of qualified hybrid vehicles to apply for a permit to use HOV lanes and HOT lanes with a single occupant. Qualified and approved vehicles must display the required HOV exemption permit and transponder. CDOT limited the hybrid vehicle program to 2,000 permits (limit reached by mid-2012). New applicants are placed on a waiting list for future consideration.

Vehicle eligibility policy for I-70 East TEL's will adhere to the same vehicle eligibility policy adopted on I-25 and US 36 TEL's and will be restricted to the following vehicles:

- **Single-Occupant Vehicles** will pay the applicable toll rate, either by Colorado interoperable toll transponder or license plate tolling.
- **High-occupancy vehicle** customers meeting the requisite occupancy requirement of two or more persons (HOV 3+) and carrying a switchable toll tag set in the appropriate carpool setting will not be charged a toll for use. HOV customers without a switchable transponder, one incorrectly set, or a malfunctioning unit will be charged the prevailing toll rate.
- **Trucks and multi-axle vehicles** will pay the applicable toll rate, in addition to a vehicular surcharge established by HPTE.
- **Registered hybrids** carrying a transponder will not be charged a toll.
- **Motorcycles** meeting state requirements qualify as a high occupancy vehicle and will not be charged a toll.
- **Buses and vanpools** will not be charged a toll at any time.
- **Emergency and enforcement vehicles** will not be charged a toll and will not require a transponder, provided they are responding to a dispatched event.

Vehicles not allowed in the TEL's include:

- Bicycles, pedestrians, and other non-motorized vehicles
- Funeral processions

7.1.3. Vehicle declaration

As shown in Chapter 4, self-declaration (switchable) transponders will be used as a means of meeting CDOT's HOV objectives for all express lanes (including I-25 and US 36). The switch sends two different tag IDs, with the specific ID sent based on the prevailing switch setting. With the use of the self-declaration toll tags, this yields the following toll classifications of users:

- Full toll rate charged for SOVs
- No charge for three-or-more-person vehicles (HOV 3+) when set appropriately

7.1.4. Exemptions

Exemptions may be granted to the regional regulations and business plan policies affecting the operation of the I-70 East TEL's. For example, exemptions could be granted for hours of operation, user groups included or excluded, tolling strategy, account management, access, or other parameters. Any exemptions granted will be approved by the appropriate oversight agencies (CDOT, HPTE, RTD, and DRCOG). Exempt vehicles will be provided non-revenue transponders.

7.1.5. Evolution of HOV and HOT lanes

According to Section 166, Title 23 of the United States Code, an express lane is considered degraded if it fails to operate at a speed of 45 mph 90 percent of the time over a period of 180 consecutive days during morning and/or evening peak periods. If this occurs, MAP-21 recommends that express lane policies evolve to recover the mandated operational performance aforementioned. Actions to improve the performance of express lanes include enhancing enforcement, altering access by Inherently Low Emissions Vehicles (ILEV) and hybrids, increasing occupancy, establishing tolls (if not already done), and raising tolls on additional vehicle classes. Hence, agencies ought to continuously monitor traffic demand and performance of HOV/HOT lane. As

HOV/HOT demand increases over time, a common practice is to alter occupancy requirements to maintain efficient operations.

I-70 East TEL's levy a toll on SOVs and allow HOV 3+, transit, and other toll-free eligible vehicles access to the TEL free of toll. Figure 7.2, below, depicts the evolution of an HOT/HOV lane throughout the years. The vertical axis represents the traffic volume as a percentage of the critical operating threshold. The horizontal axis represents the time lapse from the onset of operations in the HOT/HOV lane. Examining point (A) in the figure shows that use of the lane by HOV 2+ and exempt vehicles increases over time and yields less capacity for toll-paying customers (SOVs). Eventually, SOVs will not be able to access the lane as long as HOV 2+ users are allowed free access. The more the HOV ridership increases in the express lane, the less easily tolls are able to manage traffic demand. Over time, say year X2 for illustration in the figure, growth in HOV and other exempt vehicles will exceed capacity. At this point (C), agencies must implement tolls for SOV and HOV 2+.

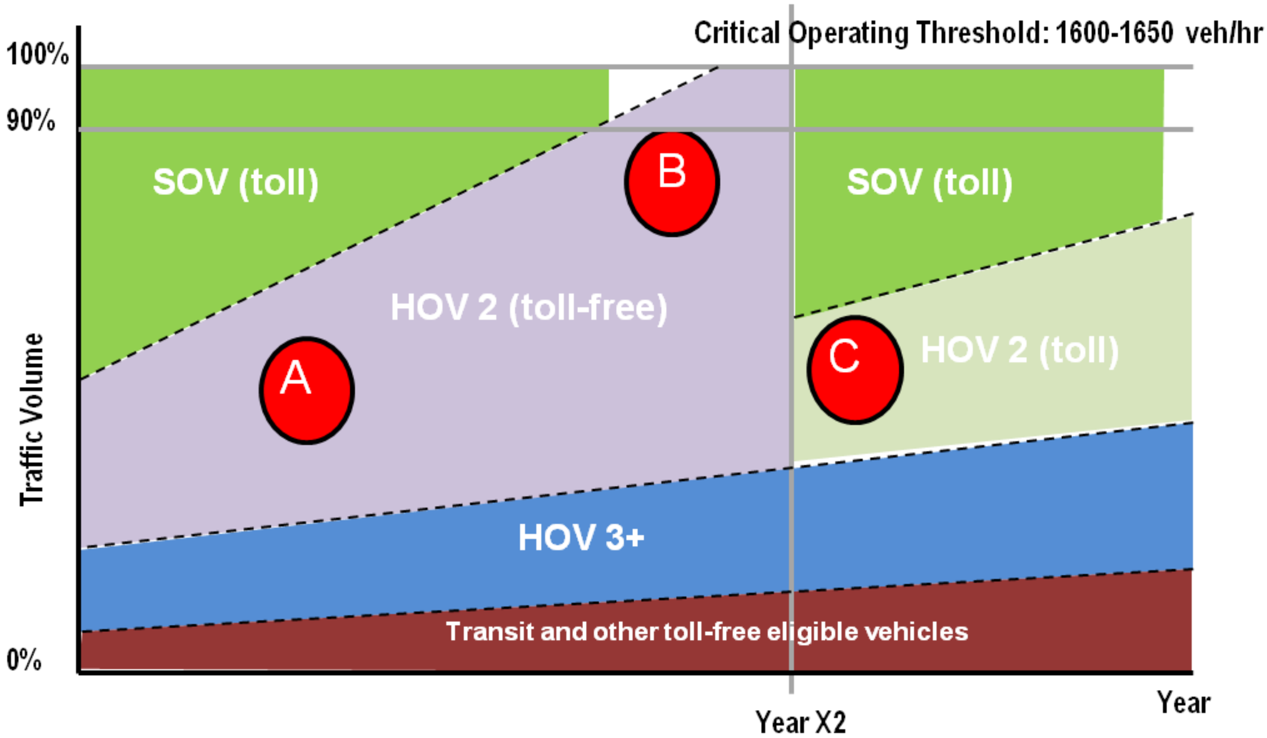


Figure 7.2: Progression of HOT Lanes (Reproduced From: Swisher et al., 2003)

7.2. Operational Scenarios

The selected operational scenarios are intended to cover situations that are anticipated to be encountered. This ensures that all operational scenarios have been considered in defining the proposed procedures of the system.

7.2.1. HOV users with a self-declaration transponder

HOV users with switchable transponders will need to set their transponder to "HOV." This will allow the tolling system to identify them as HOV and not assess a toll. HOV users with an existing form-factor or sticker transponder issued by E-470 or with a switchable transponder set to "TOLL" will be assessed the posted toll rate regardless of their occupancy status (see Chapter 4 and Figure 4.5).

7.2.2. SOV users with a transponder

All SOV users that have a switchable transponder will need to set their transponder to "TOLL" to declare themselves as SOV users to the tolling system. SOV users with other types of transponders will be identified by the system and assessed a toll.

7.2.3. HOV and SOV users without a transponder

For all users without a transponder, license plate tolling will be used. Since current technology cannot determine the occupancy status of a vehicle, HOV and SOV users without transponders will be treated the same and will be assessed a toll. However, tolls collected via license plate tolling will be higher than those collected via transponders to cover the additional back-office processing cost. As a result, users who are assessed tolls via license plate tolling will be encouraged to obtain transponders to save cost for both the user and the back-office.

7.2.4. Exempt vehicles: RTD buses, motorcycles, and registered electric/hybrid vehicles

RTD vehicles and motorcycles will be allowed to utilize the express lanes without paying a toll. They will each have a special transponder that identifies them as transit/motorcycle vehicles to the tolling system.

7.2.5. Multi-axle vehicles

Multi-axle vehicles will be permitted to access the I-70 East TEL's at the prevailing toll rate. As is currently featured on the existing TEL's (I-25, US 36), these vehicles will be subject to an additional surcharge as established by HPTE.

7.2.6. Emergency response vehicles

Emergency response vehicles that are actively responding to an emergency will be exempt from paying tolls to use the express lanes when responding to an emergency.

7.2.7. Courtesy Patrol and snow plows

Courtesy Patrol vehicles and snow plows that have a contract with CDOT will be exempt from paying tolls to use the express lanes. Similar to RTD transit vehicles, they will be provided transponders and coded in the system to identify them as exempt vehicles or be reimbursed for tolls.

7.3. Operational Requirements

The I-70 East TEL's will be managed by CDOT, transit operations will be maintained by RTD, and enforcement will be managed and conducted by the CSP.

CDOT may appoint an Express Lanes Operations Manager (ELOM) who will oversee all system operations, incident management, and maintenance activities at the CTMC in Golden. CSP will provide an enforcement supervisor, who is responsible for overseeing all CSP and/or municipal police officers assigned to enforcing the occupancy and separation provisions of the express lanes.

Whenever it is deemed necessary by CSP, the operation of the express lanes may be suspended. This may be due to the presence of a corridor-wide incident, an incident within the express lanes, severe weather, debris that impedes traffic, and other unsafe conditions. All suspension decisions will be made with the ELOM and in coordination with RTD. The ELOM will ensure that changes in toll collection, including transaction nullification, are in keeping with the process identified in this Concept of Operations document.

7.3.1. Express Lanes Operations Manager

The ELOM will be based at the CTMC in Golden, and will supervise all express lane operations, including:

- Coordinate work between CDOT, RTD, HPTE, and other entities with a responsibility for express lanes delivery and operations
- Assist with construction, maintenance, and capital equipment installation
- Monitor express lanes level of service and conduct speed and travel time studies to meet federal standards
- Provide recommendations to HPTE to improve the express lanes' performance
- Coordinate incident response strategies
- Monitor operations by radio

- Log all information pertaining to incidents or requirements for toll nullification
- Relay information to traffic service entities and transportation agencies
- Manage maintenance contracts for inspection, rehabilitation, and other maintenance of the toll collection system

7.3.2. Operations

Operations personnel are assigned to the express lanes by the ELOM. This may include CDOT, RTD, or vendor operators, who, in turn, will respond to field operations and maintenance repair issues. Each operations crew for each shift completes the appropriate safety checklist, and submits the appropriate safety checklist daily to the ELOM. Crews also will complete an Express Lanes Incident Report, as necessary.

Operators will be responsible for checking the lanes for disabled vehicles, coordinating the removal of disabled vehicles from the lanes, coordinating the removal of hazardous debris from the lanes, and completing incident reports as required.

7.3.3. Enforcement

HPTE, its contractors, and others with prior approval by HPTE may observe traffic in the TEL's for the purpose of understanding and reporting on TEL's traffic operations. CSP and/or municipal police supervisors of each shift are responsible for the direct supervision of the police officers for the TEL's. The police officers will patrol the TEL's and monitor their operation from positions as directed by the police supervisor. Officers in the field will assist in the opening and closing operations of the TEL's, as required.

Police officers will facilitate the movement of vehicles using the TEL's, enforce rules and regulations, and enforce traffic laws under Colorado law.

7.3.4. Communications

All express lanes personnel responsible for operations will have the capability to communicate with the ELOM and CTMC via radio, cellular phone, and other acceptable means of voice communication. Every operator by ELOM assignment will have a specific call number, to be used for communicating with various express lane departments, including ELOM, CTMC, CSP police dispatch, and police on Courtesy Patrol.

A light-duty and/or medium-duty Courtesy Patrol vehicle will be made available for the purpose of removing disabled vehicles on the express lanes. All operators should receive proper training in correct towing procedure for the express lanes. The Courtesy Patrol operators are responsible for removing stalled or disabled vehicles from the express lanes to a safe location where the owner can obtain further assistance. In the event of a disabled RTD bus, a heavy-duty wrecker is dispatched to transfer the bus to the assigned bus operating facility. When a private bus is blocking the express lanes, the wrecker operator will remove the bus to an appropriate location off the express lanes.

8. Enforcement

This section addresses the role of law enforcement relative to the movement of vehicles in the I-70 East TEL's. This plan complements existing policies concerning accident investigation, traffic law enforcement, and staffing.

8.1. Law Enforcement Jurisdiction

Local law enforcement officers, operating under the authority of Colorado state statutes, possess the full authority for enforcing the policies and use of the express lanes. Figure 8.1 shows law enforcement jurisdictions within the project limits.

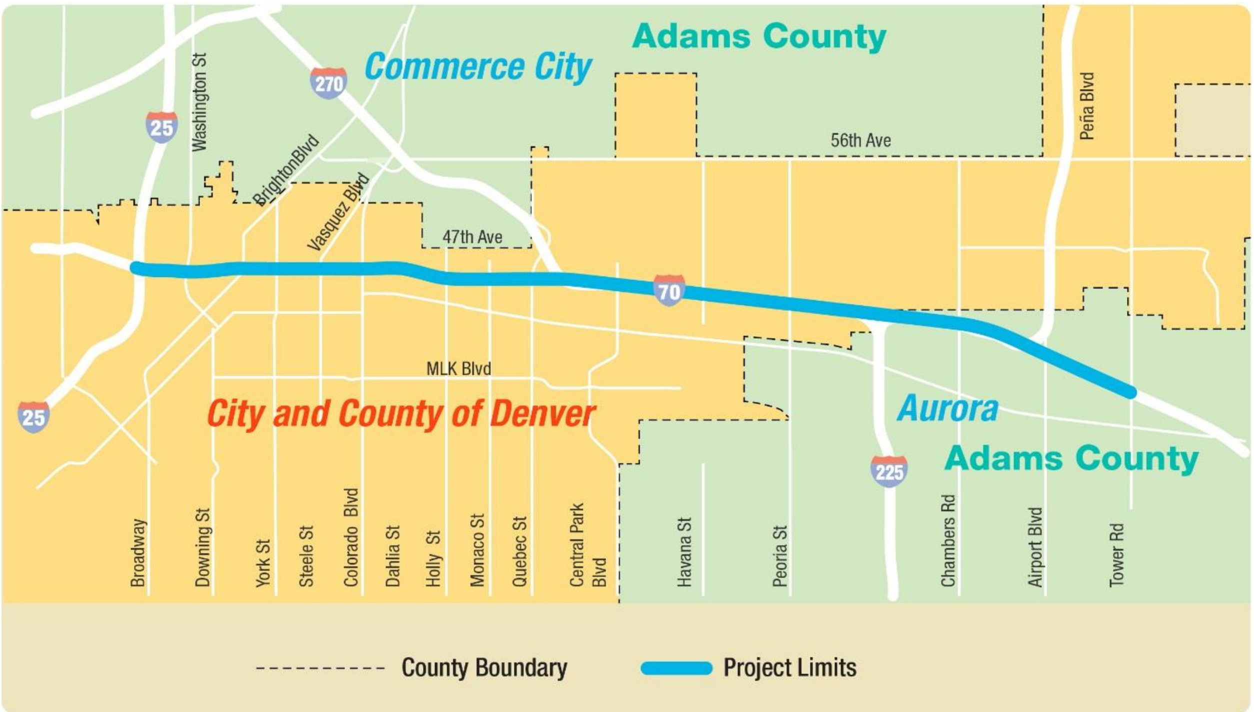


Figure 8.1: Law Enforcement Jurisdictions within the Project Limits

8.2. Express Lanes Traffic Management

Local law enforcement officers assigned to express lane enforcement operations will provide assistance for express lane personnel when a police presence is required, and also will be responsible for assisting buses, vans, and carpools authorized to use the lane. Officers will, in addition, be responsible for the enforcement of traffic laws and express lane violations during their duty hours.

8.3. Roadside Enforcement Needs

Generally, enforcement needs for TEL's are related to ensuring the legal use of the express lanes, and safe vehicle operations in TEL's and adjacent general-purpose lanes. As a result, the enforcement focus is on ensuring the customers pay the proper toll and abide by the traffic control devices, such as no passing over the double white lines. Customers who are in the I-70 East TEL's illegally are not only failing to pay their share, but also are taking away from the available lane capacity and potentially reducing the speed of operations for those paying the toll or meeting the occupancy requirements. Notice for the enforcement is provided through standard regulatory traffic control devices (signs) similar to Figure 8.2. Table 8.1 lists violation types pertaining to TEL's.

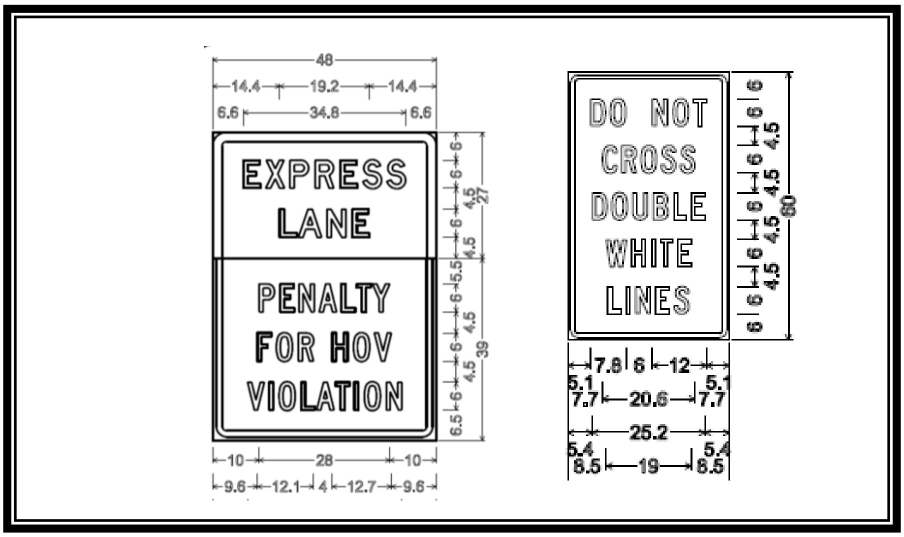


Figure 8.2: Typical TEL Regulatory Signs

Table 8.1: Violations Types

ITEM	DESCRIPTION
Occupancy Violation	Traveling the express lanes with the transponder set to HOV without meeting the HOV occupancy requirement.
Buffer Violation—Double White Line Crossing (DWL)	Ingress or egress TEL at illegal locations; crossing the solid double white line is illegal.
Toll Evasion Violation	Express lane users failing to pay LPT mailed invoices (see next section for Toll Collection Enforcement). HOV violators, obscured tag violators, and buffer violators also may commit the offense of Toll Evasion.
Toll Avoidance Enforcement	Obscured license plate to avoid paying tolls.
Other Traffic Enforcement	Speeding, careless driving, etc.

HPTE, its contractors, and others with prior approval by HPTE may observe traffic in the express lanes for the purpose of understanding and reporting on express lane traffic operations. This can include flow rates, congestion levels, general observation of flow and operating conditions, as well as observation of vehicular occupancy. However, only officers from the CSP or local law enforcement agencies are authorized to issue traffic citations on the express lanes.

8.4. Roadside Enforcement Technologies (Technical Aids)

Vehicle occupancy and buffer crossing enforcement will be undertaken utilizing the then-current state of the practice for safe and efficient enforcement. At the time of developing this report, a national scan of available technologies was conducted and is summarized in Table 8.2.

Table 8.2: National Scan of HOV and Buffer Violation Enforcement Technologies (as of January 2015)

STATE/AGENCY	BUFFER VIOLATION TECHNOLOGY	HOV VIOLATION TECHNOLOGY
CA **BAIFA Bay Area**	No buffer or special striping (just skip stripe) except for areas where lane changes are not safe, in which case there is a double stripe.	OSI: Beacons will alert officers to vehicles declaring high occupancy. A web portal allows officers to enter a transponder ID and check the declared status of the vehicle at prior read points.
CA **LA Metro** **I-110/I-10**	Double white striping separates the express lanes from general-purpose lanes and officers observe violation (Illegal crossing).	FasTrak with HOV or Solo driver settings.
CA **SANDAG San Diego** **(I-15)**	No technology, concrete barrier separates express lanes from general-purpose lanes.	TSI indicator light reads green, blue, and amber, which indicate either valid read, invalid read, or no read. Registered carpool and SOV pays full fare.
CO **I-25**	None. Barrier-separated facility	None. Two reversible lanes; one HOV and one SOV, and officers enforce visually vehicle occupancy in the HOV lane.
FL **95 Express**	No technology, tubular delineators separate express lanes from general-purpose lanes, officers observe violations	Registered car pool only, TT customer must complete application & follow guidelines for carpools. TT customers have to “bag”/shield their TT when traveling with 3+ carpools. No technology is used to support occupancy verification.
GA **SRTA Atlanta** **(I-85)**	Tolling gantries are located every half mile within a tolling segment. Thresholds for transponder reads are set for each segment to determine if a vehicle was travelling within the segment or illegally entered a segment, if a vehicle illegally entered the segment, then a $25 DWL fine is issued by the system.	Customer must have an ETC account (Peach Pass) and an HOV 3+ customer must self-declare what mode they are travelling in. Customer declares occupancy via mobile app, online, or calling the CSC, at least 15 min prior to travel on the I-85 express lanes. Customers receive a text/email confirmation. Data file sent to officers every 5 to 10 min. Patrol vehicle equipped with ALPR which scans license plates that match HOV list. If match occurs, on-board CAD computer emits an alert to officer. Officer visually verifies occupancy.
MN **I-394**	NA	Patrol vehicles equipped with RFID readers that scan while stationary or patrolling lanes and can determine if vehicle is in HOV mode, officer can pull over if vehicle is not HOV and issue ticket
TX **TEXpress Dallas**	No technology, concrete barrier separates express lanes from general-purpose lanes.	Customer must have ETC account. They use an App to declare HOV. Real-time registration made available to law enforcement agencies
TX **Katy (1-10) Houston**	No technology, tubular delineators separate express lanes from general-purpose lanes, officers observe violations	None. Separate lanes are provided for HOV/SOV + transponder.
TX **DFW Connect Dallas**	No technology, concrete barrier separates express lanes from general-purpose lanes.	App used to declare HOV. Customer have option for ETC or pay my mail rates
TX **Cesar Chavez** **El Paso**	No technology, pavement striping separates express lanes from general-purpose lanes.	None
UT **I-15**	No technology, pavement striping separates express lanes from general-purpose lanes, officers observe violations	Express Pass with HOV and non-HOV settings on transponder
VA **I-495/I-95 Exp.** **DC Area**	Soft barrier (channelizes) separates express lanes from general-purpose lanes No movement into lanes permitted except at interchanges.	Transponder status (Flex or regular E-Zpass mode) read at each gantry. VA State Police have hand held transponder interrogators to determine mode transponder is in.
WA **SH 167**	No technology. Used to have DW striping separate the express lanes from GP lanes & law enforcement officers observe violations. Now, most of the corridor has a single stripe & drivers can get in and out at almost any point.	No technology. HERO Program; hotline for driver reporting of violators. First-time HOV lane violators are sent an educational brochure. Second-time HOV lane violators are sent a letter from WSDOT. Third-time HOV lane violators are sent a letter from the Washington State Patrol.

8.5. Toll Collection Enforcement

8.5.1. Leakage/lost revenue

Procedures and mechanisms will be developed by HPTE and the toll system integrator to minimize leakage and lost revenue from the express lanes. These must include mechanisms for vehicle identification and toll collection, field enforcement, collection of past due accounts, and auditing procedures to effectively report the status of all transactions and revenues (Figure 8.3 shows typical leakage sources).

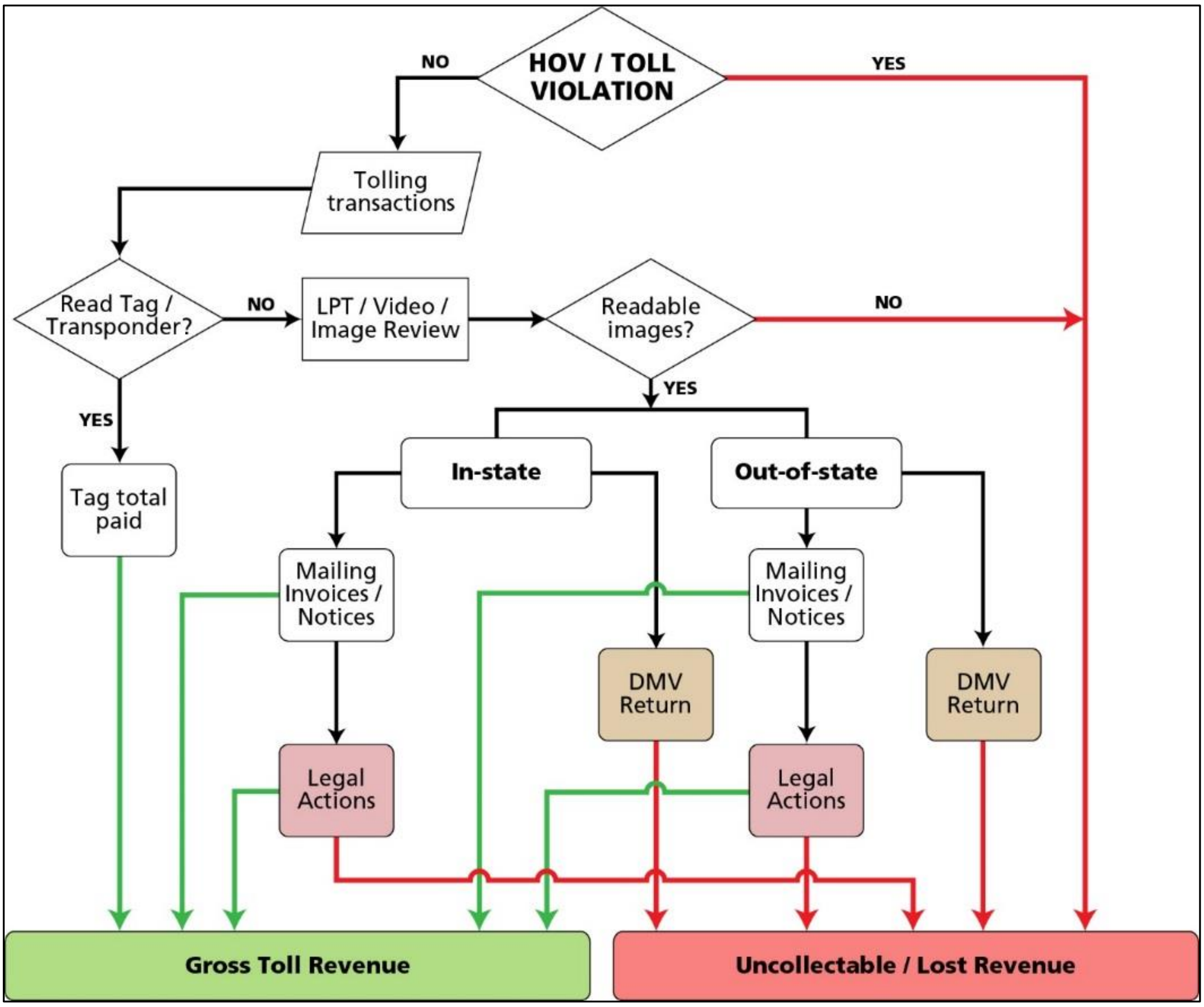


Figure 8.3: Typical Toll Collection Leakage Sources

8.5.2. Penalties and fines

Penalties and fines as adopted by HPTE policy will be enforced for express lane use. Figure 8.4, next page, shows the existing toll violation process in use by E-470. It should be noted that E-470 and HPTE initiated a Vehicle Registration Hold (VRH) program authorized by Colorado state law to request that the Department of Revenue Division of Motor Vehicles place a hold on vehicle registrations of vehicle owners who have not paid their tolls, fees, and civil penalties. The most common strategy for full traffic stream observation among early express lane projects involves the use of stationary enforcement zones or roving patrols that allow enforcement officers to check vehicle occupancy, and for vehicles not meeting occupancy requirements, verifying the toll payment. Requiring all vehicles to carry a transponder and "declare" their HOV status through the transponder switch setting reduces the number of traffic stops required. For the I-70 East TEL's, traffic stream observation will include the use of emerging technologies to partially automate enforcement through license plate recognition (LPR) for video payment and account registration.

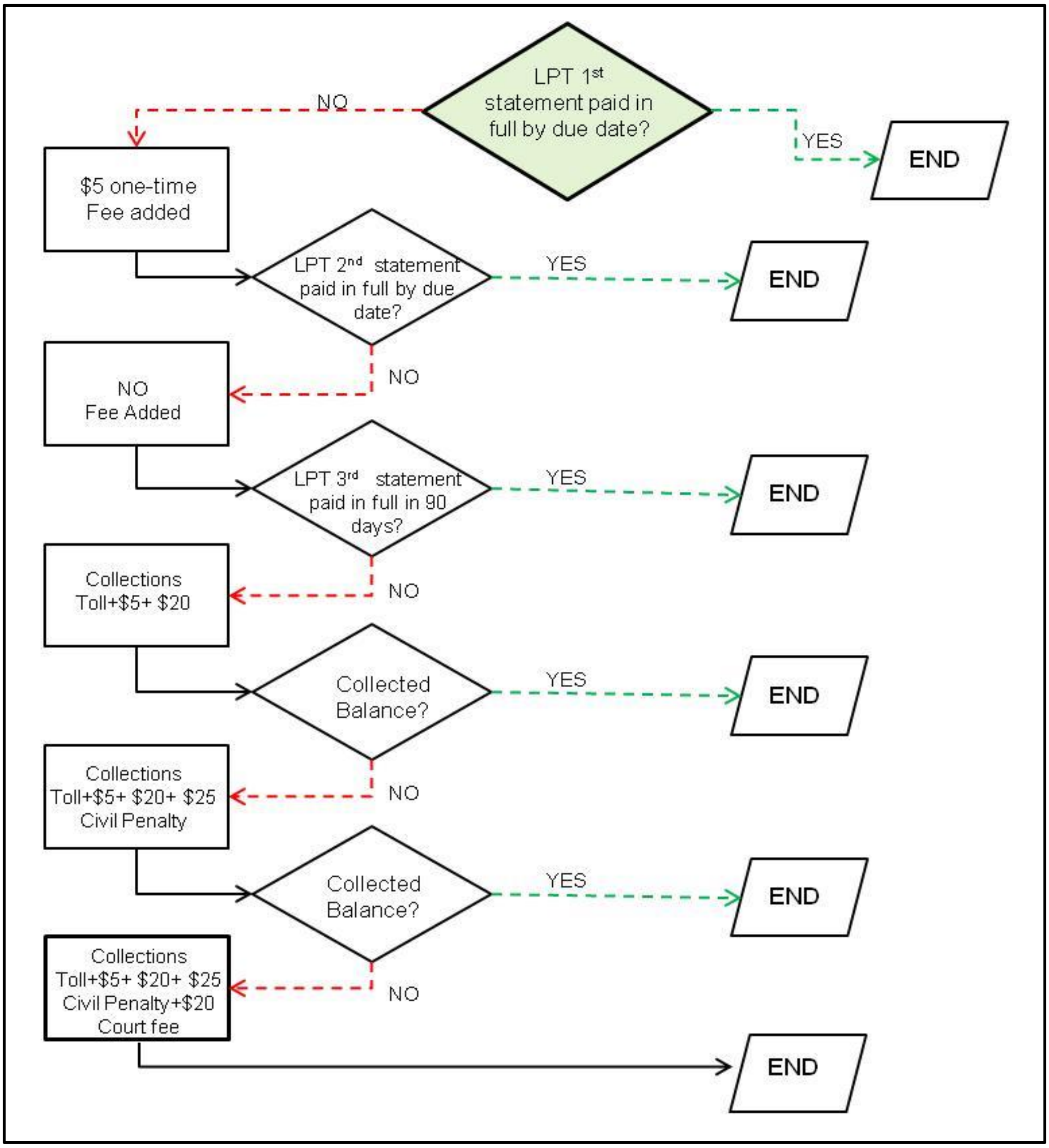


Figure 8.4: E-470 Violation Process

8.6. Enforcement Plan

An enforcement plan is needed for I-70 East TEL's to provide guidance on (1) enforcement needs, (2) enforcement guidelines, (3) Technology procurement, (4) enforcement contracting, (5) enforcement training, and (6) implementation (see Figure 8.5).

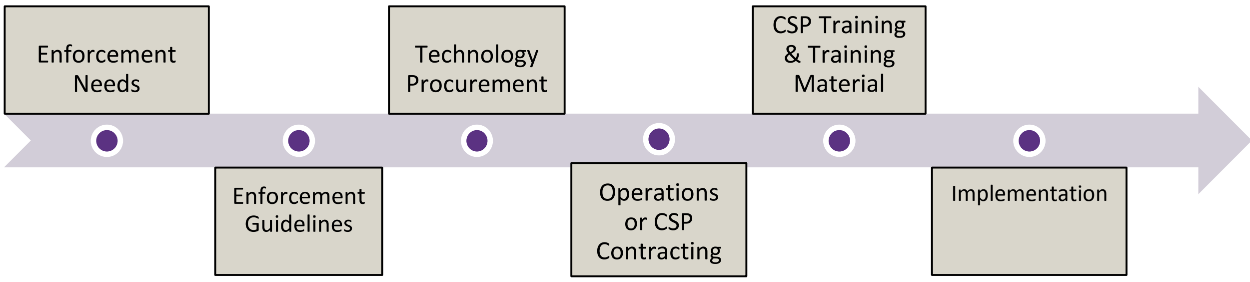


Figure 8.5: Enforcement Plan Processes

9. Incident Management

9.1. Incident Management for Tolled Express Lanes

Incidents in express lanes and adjacent general-purpose lanes can result in long delays as well as safety concerns from debris and secondary accidents. Toll-paying customers expect an enhanced level of service during recurring congestion (i.e., peak hours) and during non-recurring congestion (i.e., incidents, special events). An effective incident management plan for priced express lanes provides travel time reliability and an enhanced level of service for traffic safety and mobility. Integrating a succinct incident management process and continual monitoring and evaluation of travel time are key proactive measures for the success of priced express lanes (see Figure 9.1).

The FHWA Priced Express Lanes Guide provides general guidance for incident management within express lane facilities and strongly recommends that express lanes be equipped with incident surveillance and detection equipment, monitored by observant (and preferably dedicated) staff at least during periods of peak demand. Staff must be fully trained and experienced in express lane incident response with drills and exercises to improve responsiveness and safety. If construction is anticipated in the proximity of express lanes, the Guide further recommends 24-hour service patrols, temporary collision investigation sites, immediate-tow rules and procedures, and agreements with construction contractors to assist in clearance of debris. These requirements serve as the backdrop for the incident management concept of operations.

Figure 9.1: Incident Management Process

9.2. Traffic Incident Management Response Manual Component

Currently, there is no incident management plan for I-70 East within the project limits. An incident management plan is needed for both the general-purpose lanes and TEL's. The incident management plan for the TEL's must address the following at a minimum:

- Definitions of incident levels
- Scene management guidelines
- Emergency access and staging areas
- Communication protocols
- PIO contact list

- Alternate route information

9.3. Lane Blockage (Vehicle Breakdown)

A vehicle breakdown will affect the operation of the express lanes and must be addressed as soon as possible. CDOT and CSP will coordinate their activities in providing traffic control and having the vehicle removed from the lane. All activities will be coordinated through the CTMC. CDOT will utilize Courtesy Patrol vehicles during peak periods to provide motorists assistance and help quickly clear disabled vehicles.

9.3.1. Partial lane blockage

When a partial lane blockage has been identified by the CTMC:

- Local law enforcement dispatch will direct a police unit to the scene to provide traffic control and assistance if police presence is required at the scene.
- Local law enforcement will direct a tow vehicle to the scene, if needed. For safety, the tow vehicle will approach the breakdown from the upstream direction.
- When directed by local law enforcement, the tow vehicle will remove the vehicle to an off-site location.

If the blockage is caused by a bus, it may be necessary to off-load passengers. In this case:

- Local law enforcement directs a tow vehicle suitable to tow RTD buses to the scene.
- RTD dispatches an empty bus to the scene.
- The bus approaches the scene from the upstream direction and stops in the center of the lane behind the disabled bus.
- Under the direction of the police officers, passengers then are safely transferred from bus to bus.
- The tow vehicle operator then removes the disabled bus from the lane to an off-site location as determined by RTD.

9.3.2. Complete lane blockage

If the incident results in a complete lane blockage:

- Local law enforcement dispatch will direct the most currently available police unit to proceed to the upstream entrance to the lane and temporarily close the entrance at the point the double white stripe begins (if location is appropriate to the incident).
- CDOT personnel follow the operational procedures for a lane closure, changing signage to “CLOSED” with CTMC.
- Local law enforcement will dispatch a tow vehicle to the scene, if needed. The tow vehicle will approach the breakdown from the upstream direction.
- When it has been determined that traffic has cleared the lane upstream from the blockage, the tow vehicle will proceed to the blockage location from the upstream direction. The tow vehicle will remove the disabled vehicle to an off-site location.
- If the breakdown involves a bus, off-loading procedures will be followed as outlined in the partial lane blockage section.

9.4. Responsible Parties

The developer will prepare Traffic Incident Management Plans for both the construction period and the operations period with CDOT’s cooperation.

10. Electronic Toll Collection System

10.1. High-Level System Functional Requirement

The following are the high-level system requirements for a typical tolling system applicable to the I-70 East Tolled Express Lanes:

- **All Electronic Tolling**—The toll collection system must provide for All Electronic Tolling (AET) in an open road multi-lane free-flow (MLFF) environment. Vehicles must be able to proceed past the tolling points at the posted highway/toll facility speed limits.
- **AVI Technology**—The toll collection system must utilize AVI technology at the time of implementation, as well as maintain historical compatibility for the existing ExpressToll tag base. The toll collection system also must have a migration path to any potential replacement of AVI technology and protocols.
- **Vehicle Separation**—The toll system must provide for appropriate vehicle separation in the lanes to ensure that highly accurate transactions are captured with respect to the toll facility's vehicle classification structure.
- **HOV self-declaration**—Drivers in the TEL must self-declare their occupancy status using the two-state Colorado switchable transponder provided by Neology.
- **HOV violation enforcement system**—Emerging automated HOV enforcement systems must be vetted and considered for addition to the tolling system. Otherwise, manual enforcement with technical aids must be used for HOV enforcement.
- **ExpressToll Transactions**—The toll system must support ExpressToll transactions generated via the reading of ExpressToll tags in the toll lanes and/or shoulders of the toll collection zone.
- **Video Tolling**—The toll system must support the operational requirement that the detection of a vehicle without an AVI transponder will result in an image toll transaction.
- **Vehicle Correlation**—The proper AVI or video read must be assigned to the correct vehicle with the correct classification.
- **Vehicle Classifications**—The toll system must support Automatic Vehicle Classification (AVC) in the toll zone and support multiple vehicle classes consistent with the published classifications.
- **Class Mismatches**—The toll system must detect class mismatch conditions, whereby the vehicle classification encoded on the transponder does not match the classification as determined by the toll system AVC sensors.
- **Signage**—The toll collection system must employ VTMS to display applicable toll rates to prospective customers prior to their entering the TEL's.
- **Hot-List Alerts**—The toll collection system must have the ability to support a Hot-List capability for flagging distinct license plates or tags as being "of interest" for toll evasion enforcement. When a vehicle bearing a tag or license plate that is on the Hot-List is detected passing through a toll lane, the system will generate a real-time message to appropriate staff.
- **Audit and Reconciliation**—The toll collection system must provide a comprehensive audit and reconciliation capability that will allow authorized staff to reconcile all transaction activity and to perform necessary audits on transaction activity to ensure that funds are protected and accounted for.
- **Customer Notices**—The Back Office System (BOS) must provide for all invoicing/violation noticing, accounts receivable functions, and statement updates including aging of invoices and escalation of invoices to violation status. To the greatest extent possible, the BOS must allow for customers to view their accounts via the Web, make account updates and adjustments where appropriate, and make payments via the Web.
- **Customer Service Center Interface**—A Customer Service Center (CSC) must manage all ExpressToll and/or video accounts. Storefront operations could be co-located for customer convenience and to avoid confusion. There could be multiple storefronts offered throughout the region, each being able to address both ETC and video customers. The toll collection system will interface with the CSC(s) to exchange the various types of data required to support toll collection and

administration. Of particular interest is the functionality in the BOS to process image tolling transactions and to invoice customers and potentially debit the accounts as soon as possible if a pre-paid image toll option is made available.

- **Discount Programs**—While not part of the initial operations, the toll collection system must allow for the implementation of functionally robust discount programs.
- **Maintenance Management**—The toll collection system will provide for effective management of system maintenance functions (MOMS), including capabilities such as: diagnostic support, system health monitoring, alert tracking, work order documentation/tracking, preventive maintenance scheduling, and spare parts inventory management. For existing TEL's, the MOMS system is managed by the E-470 back office without interface with the CTMC. A maintenance management plan must detail information sharing between E-470 and CTMC.
- **Network**—The toll collection system will utilize its own Local Area Network (LAN) at each toll point facility and at the Toll Operations Center. The toll point facilities and the central computer site(s) will be interconnected via a Wide Area Network (WAN). The central computer sites, including toll transaction hosts, CSCs, and other operations centers, will be connected via a WAN.
- **Fiber Optic Communications**—Traffic management and toll collection systems must be interconnected with the CTMC to share data, video, and other communication as needed and support integration with ATMS, or current and future systems, through an agreed-upon interface protocol.
- **Data Sharing**—Data and information will be shared between the E-470 back office and CDOT operating entities to support roadway and incident management, as well as toll transaction processing and administration.
- **Toll Point Management**—The system will provide for a comprehensive toll point management function to allow authorized staff to monitor and control selected toll points and to manage access cards.
- **System Reliability, Availability and Accuracy**—The system will be highly reliable with redundant components where possible to reduce the opportunity and risk of a single point of failure. In addition to redundancy, physical location separation of redundant components from primary components is desirable with respect to the toll transaction hosts as well as CSC servers. Equipment should have high Mean-Time-Between-Failure (MTBF) rates. The system also will have a high availability rate. All equipment should require low frequency preventive maintenance. All equipment should have low Mean-Time-To-Repair (MTTR) rates. The system should have a superior accuracy rate.
- **System Security and Audit**—The system will be highly secure and auditable. It will incorporate both physical and software-based security and access controls to prevent unauthorized access, and to track all authorized access. It will provide for comprehensive audit trails of all activities, including maintenance activities.

10.2. Project Level System Architecture/System Overview

10.2.1. All-Electronic Toll Collection System (AET) overview

The overall ITS and tolling system will be composed of five major elements, as illustrated in Figure 10.1, which include the following:

- **Tolling Back Office Component** (Centers, Toll Administration)—Supports payment processing, toll account management, revenue collection, and violation enforcement
- **Tolling Roadside Toll Collection Component** (Field, Toll Collection)—Roadside and central transaction host computer components that support the collection of tolls, toll rate scheduling
- **Communications Component** (Fixed Point to Fixed Point Communications)—Provides data connectivity and networking between various system elements both internal and external
- **Traffic Management System Component** (Centers, Traffic Management)—Supports traffic management, provides system monitoring, provides traffic detection, measures traffic volumes, speeds and Levels of Service in the Project area, manages incidents, and provides traveler information

- **Traffic Management Roadside Devices Component** (Field, Roadway)—Roadside equipment that supports detection, surveillance, traveler information and management of traffic

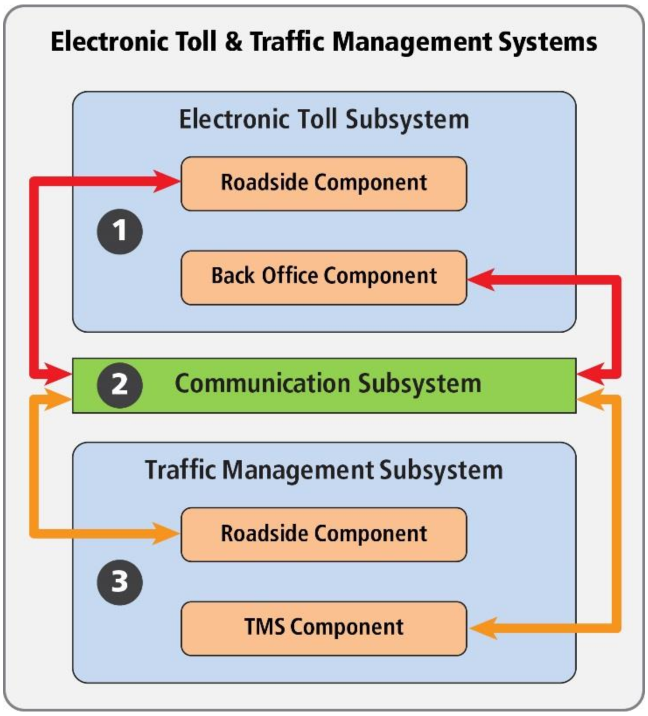


Figure 10.1: Electronic Tolling and Traffic Management (ETTM) Systems

The tolling system uses a combination of centralized and roadside (distributed lane-level) systems, with the roadside systems communicating to the vehicle-based transponder. In looking at the tolling component, Figure 10.2 illustrates a representative tolling subsystem in more detail. The details of the design will depend on the integrator selected. Remote monitoring of both tolling back office and field operations will be supported. The ETTM host (toll host) will communicate with the toll roadside equipment and the ETTM host/toll back office system will process transactions and manage the interfaces with respect to tolling.

Figure 10.2 shows data paths for a two-tier versus three-tier tolling subsystem. As shown, when the transaction is created by the Toll Zone Controller, depending on the final toll system architecture (i.e., two-tier or three-tier) it may be either sent directly to the Toll Transaction Host Computer for processing, or collected and stored by the Tolling Point Server and then sent up to the Transaction Host.

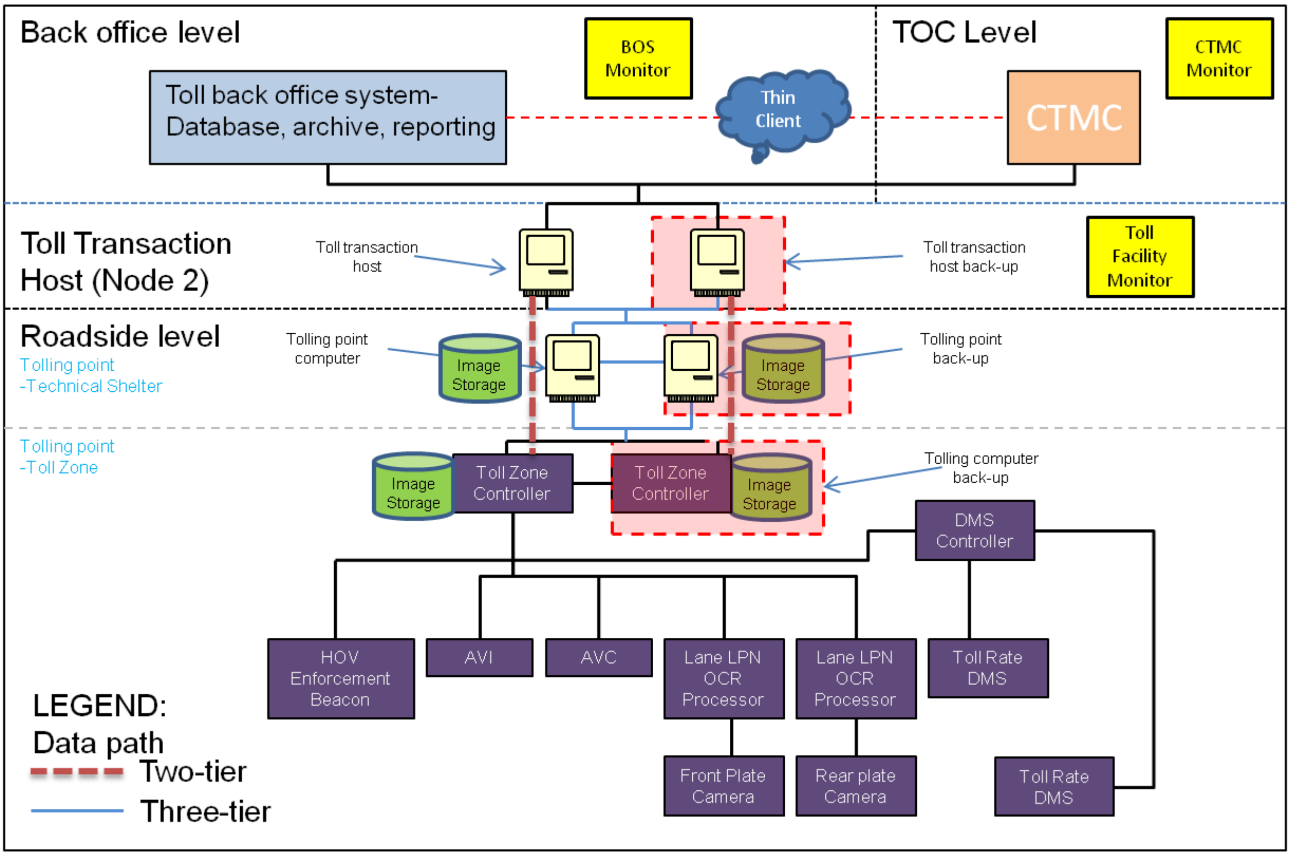


Figure 10.2: Two-Tier Versus Three-Tier Typical Tolling Subsystem

A **three-tier** toll system architecture (blue data path in Figure 10.2) in general allows the toll zone controller to focus exclusively on transaction creation and controlling the toll zone activities, while the tolling point server collects transactions from multiple toll zones at the same tolling point and handles additional tolling point applications less related to the toll zone. With **two-tier** toll system architecture (red data path in Figure 10.2), all toll zones regardless of their proximities to each other would report directly to the Transaction Host and the toll zone controllers would handle more activities than just creation of toll transactions.

In the event that communications are lost, transaction data will be stored locally and, when communications are restored, the data will be transmitted to the Toll Operations Center's central components (toll host and back office systems). The tolling system uses a combination of centralized and roadside (distributed lane-level) systems with the roadside systems communicating to the vehicle-based transponder. The details of the design will depend on the system integrator selected. Remote monitoring of both tolling back office and field operations will be supported. In three-tier system architecture, the toll transaction host will communicate with the toll roadside equipment, and the toll host/toll back office system will process transactions and manage the interfaces with the CSC and video processing center (VPC) with respect to tolling transactions.

For illustration purposes, Figure 10.3 depicts the existing I-25 segment TEL's data flows: the tolling/ITS network architecture and data communication from the lane side to the tolling E-470 back office, the CTMC, and node 2 for I-25 north segment 2. It is envisioned that the I-70 East TEL's will follow the same ITS network architecture.

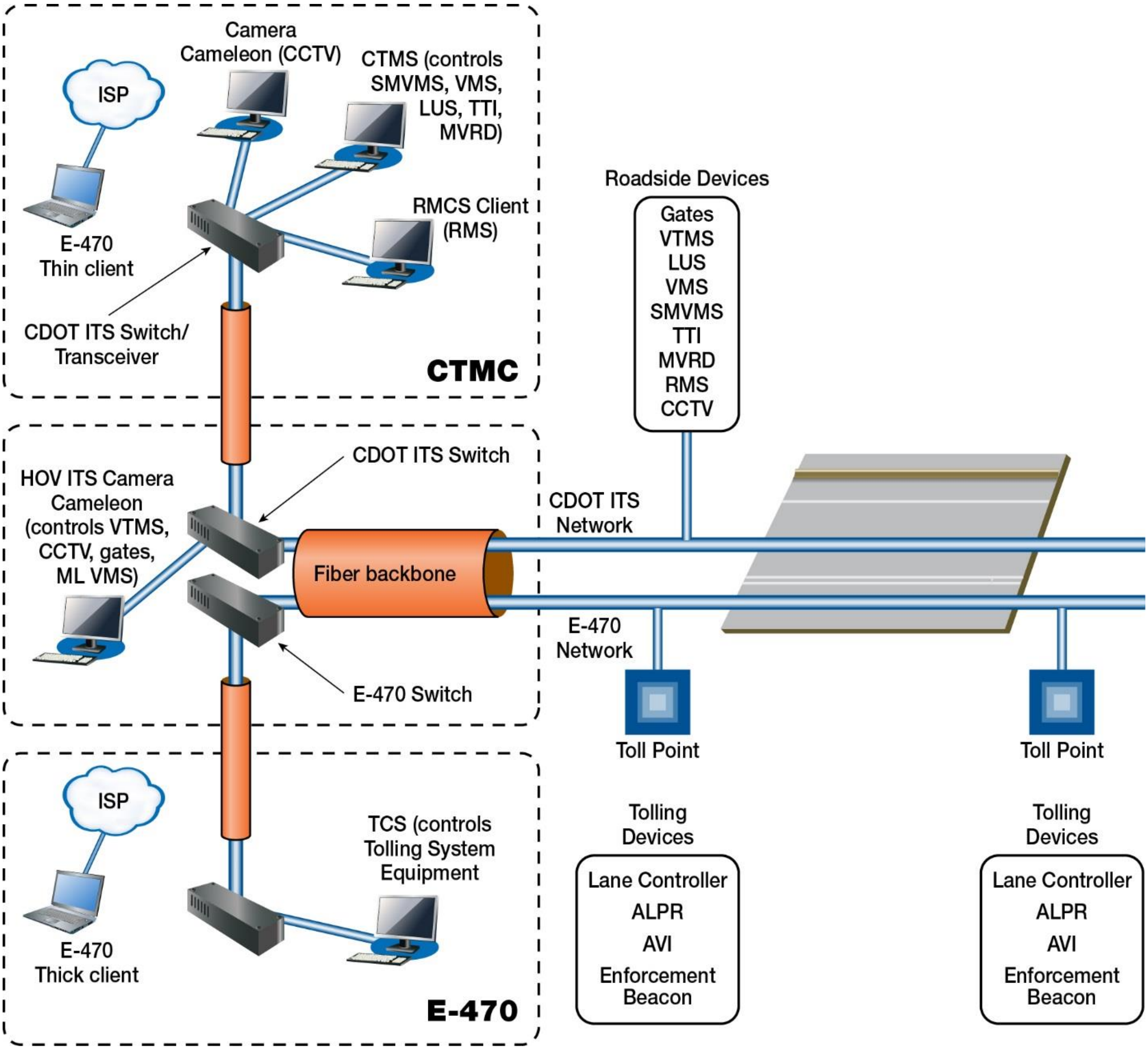
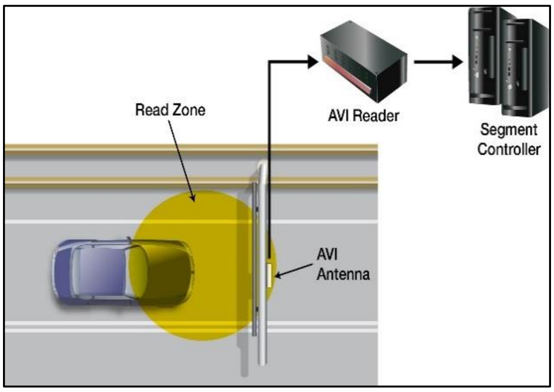


Figure 10.3: I-25 Segment 2 Data Flows

10.3. Tolling Roadside Devices Components

After the users are in the TEL, the tolling system will need to identify them and assess tolls to non-exempt users. The primary method for toll collection will be via transponders (license plate tolling is made available as a secondary means of tolling). Each tolling location will contain several components that will be mounted over/beside the TEL to either read the transponders or utilize license plate cameras to identify users.

Transponder: As discussed earlier, the preferred alternative for tolling will encourage all users (both SOV and HOV) to have switchable transponders. Vehicles without the switchable transponders will be considered SOV regardless of their occupancy status. Vehicles without a transponder will be considered SOV regardless of their occupancy status and will be assessed a LPT rate toll. HOV status is provided to the enforcement beacons. The transponders will contain ISO 18000-6C tags, which is Colorado's protocol. Readers may refer to Chapter 4 for more information.



Automatic Vehicle Identification (AVI) Reader: AVI antennas will be mounted directly above the express lane and will read the tag information stored inside each transponder. The AVI reader will need to be multi-protocol (Title 21 and ISO 18000-6C) so that it is compatible with US 36 transponders as well as Title 21 transponders currently used on existing facilities. When a toll tag is read, information will be sent to the lane controller, where it will be processed to determine if the user is an SOV or HOV.

Automatic License Plate Recognition (ALPR) Camera: For vehicles where no transponder is present or where the transponder is unable to be read, ALPR cameras will be used to obtain an image of the vehicle's license plate. When the image is taken, an Optical Character Recognition system will process the image to identify the vehicle's license plate. This information then will be sent to the lane controller. In-pavement loops will be used to signal to the ALPR camera that a vehicle is present. Additional loops will be in place to classify heavy vehicles and assess the appropriate toll surcharge.

Lane Controller: The lane controller will be housed in the tolling cabinet, which will be located in the median. It will be responsible for much of the data processing and will transmit the transponder tag and license plate information via the fiber communications network to the back-office for processing. The lane controller is designed to provide redundancy in the system. This will ensure that tolling operations will continue even during a failure in the primary processing unit. In addition, the lane controller will need to accommodate a storage system that will buffer transactions in the event that communications between the lane controller and the back-office are interrupted.

Enforcement: If the lane controller determines that a particular user is an HOV, a signal will be sent back to the tolling point to light up an enforcement beacon (see Figure 10.4). These beacons will need to be visible to officers stationed at the dedicated enforcement locations and will need to activate quickly enough to allow them to associate a beacon with a particular vehicle and then have enough time to confirm the correct occupancy. Since the flashes will be limited to HOV and exempt users (hybrids, motorcycles, etc.), it will reduce the burden on the enforcement personnel and clearly identify the vehicles where an occupancy check will need to be performed. If a user identified as HOV fails an occupancy check and appears to be in violation, the officer will pursue the offender or radio ahead to other enforcement personnel. Enforcement personnel also may be equipped with handheld readers and perform tolling point enforcement at locations other than the dedicated enforcement locations. These units will be located inside enforcement vehicles and allow an officer to scan the transponders of passing vehicles and find out when a toll transaction last occurred. If it appears that the user violated a prior tolling point, the enforcement officer may issue a citation. In addition to the tolling point enforcement, buffer violations also will need to be enforced. This will be done manually by officers patrolling the corridor. The switchable toll tag will have a red strip on the back side to indicate to the officers the tag setting.

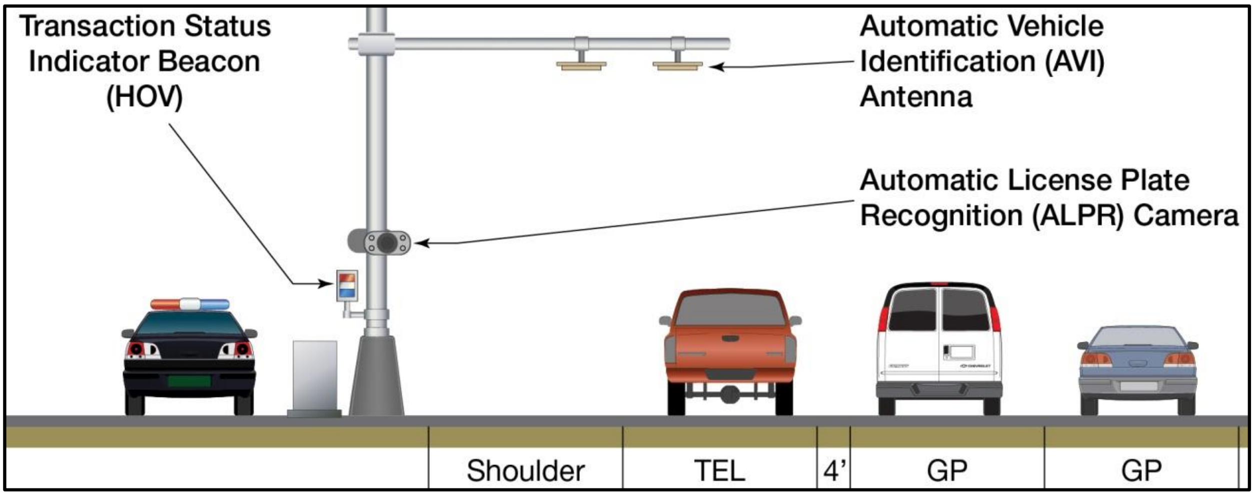


Figure 10.4: Enforcement Location

- **Customer Service Center (CSC) Back Office:** The CSC back office will receive all transponder tag and license plate information from the lane controller and assess tolls on the individual roadway users. Additional processing will be required for users tolled via license plate since the names and addresses of the registered users will need to be obtained from the State Department of Motor Vehicles. After this information has been obtained, all the tolls incurred during a specific period are aggregated and bills will be sent out to collect payment. It is expected that slightly higher tolls will be assessed for these users to cover the costs of the additional processing that will be required. . It is likely that this higher rate will also encourage users to obtain a transponder if they plan to utilize the corridor with sufficient frequency.

10.3.1. Roadside data collection

10.3.1.1. Detection of vehicle

When a vehicle uses the TEL lanes and passes through the multi-lane toll zone at an AET roadside tolling point gantry structure, the vehicle will be detected either first when the toll system reads the operable toll transponder, or second, in the absence of a valid transponder, when the vehicle's presence is detected automatically by toll devices either mounted on the toll point gantry or in the pavement near the gantry.

10.3.1.2. Initial identification of the vehicle (without a transponder)

When a vehicle passes through the multi-lane tolling zone at the roadside tolling point, a detection device will trigger the capture of video images of the front and rear of the vehicle that will include the license plate(s).

To gain an identification of the vehicle, the License Plate Number (LPN) must be accurately determined. The video images of the vehicle must be read and the LPN derived. Initially, LPN determination is attempted by automated processes using Optical Character Recognition (OCR). The OCR process checks itself and indicates a "confidence level" the system has that the resulting LPN is accurate. This process is deemed successful if the confidence level exceeds a minimum threshold (value that is configurable).

If the OCR process is successful in identifying the vehicle's license plate number, the LPN becomes part of the toll transaction when it is created by the toll zone controller computer. If it is not successful, the LPN data will not be included in the toll transaction, but the video images will be included so the vehicle LPN can be identified in the VPC by a human video image reviewer.

10.3.1.3. Classification of the vehicle

After detection of the vehicle in the roadside multi-lane toll zone, roadside tolling devices will collect data to determine the type, or classification, of the vehicle. Several vehicle classification schemes are possible, but in this case, vehicle toll classification will be based on the number of axles on the vehicle unit. Vehicle classification can be accomplished with several technologies including “smart loop” systems and laser profiler systems, or combinations of multiple technologies.

10.3.2. Transaction creation

After the necessary data are collected by devices in the roadside toll zone and sent to the lane controller, a toll transaction that accounts for the passage of a vehicle through the multi-lane toll zone is created. All toll transactions will have the same Uniform Transaction Format data structure for consistency and to facilitate more efficient data handling, data processing, and accounting as it flows higher up the toll collection system and through the interface with the Toll Back Office System for payment processing.

In high-level terms, the toll transaction should provide space for the following data:

- Date, time & location of the last toll transaction
- Vehicle classification
- ETC transponder ID number
- License plate number (if identified)
- OCR confidence level
- Video images of the vehicle & license plate
- System health data
- Other relevant data

See Figure 10.5 for a graphic illustration of this heigh-level transaction flow.

10.3.3. Roadside transaction processing

When the transaction is created by the toll zone controller, depending on the final toll system architecture (i.e., two-tier or three-tier) it may be either sent directly to the Toll Transaction Host Computer for processing, or collected and stored by the Tolling Point Server and then sent up to the Transaction Host.

A three-tier toll system architecture generally allows the toll zone controller to focus exclusively on transaction creation and controlling the toll zone activities, while the tolling point server collects transactions from multiple toll zones at the same tolling point and handles additional tolling point applications less related to the toll zone.

With two-tier toll system architecture, all toll zones regardless of their proximities to each other would report directly to the Transaction Host and the toll zone controllers would handle more activities than just creation of toll transactions.

10.3.4. Host transaction processing, accounting, and reporting

When a toll transaction reaches the Toll Transaction Host from the roadside tolling point, it is posted to one of several host accounts for revenue accounting, further vehicle identification, and processing for payment. Then, it is stored to a database. Some transactions without completed vehicle identification are sent to the back office for completion by a human video image review and analysis before they are ready for payment processing.

The Toll Transaction Host will provide reports to support the operation, maintenance and management of toll revenue collection. The system will provide the capability for configurable, ad hoc, and comprehensive reporting to support operations, accounting, management, and audit functions covering the full toll revenue collection business process from the roadside data collection to toll invoicing, payment, collection, violation enforcement, and adjudication.

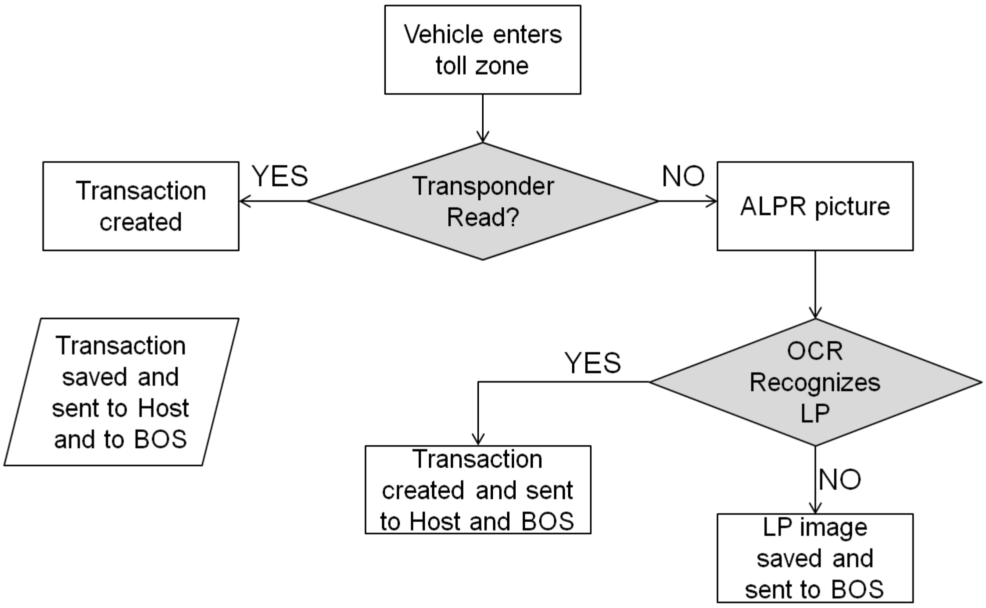


Figure 10.5: High-Level Transactions Flows

10.3.5. Maintenance On-Line Management System

The tolling system will be equipped with a Maintenance On-Line Management System (MOMS) that will monitor the health of the tolling system and perform diagnostic checks on most system components on a 24/7 basis. When a system maintenance or performance issue is detected, the MOMS will generate an alert and page the maintenance technician on duty. If no response is received in a configurable amount of time from the first alert, the system will escalate the alert up the established but configurable chain of command until the alert is noted. The MOMS will track the times required to respond to the issue/event and resolve the issue. The MOMS also will track and monitor warranty status for system elements and maintain a database of the spare parts inventory. The system will provide configurable and ad hoc reports of system performance and activities, maintenance staff performance and activities, performance of system elements, spare parts inventory, and warranty status. Currently, MOMS is housed at the E-470 facilities and is not coordinated with the CTMC. Coordination is envisioned to be established between E-470 and the CTMC for smooth maintenance operations.

10.4. Tolling Back Office Component

The Toll Back Office component of the AET system will support payment processing functions necessary for customers to pay, and Toll Back Office to collect the tolls that customers owe for use of the TEL facilities. The BOS will specifically support the following:

Customer Toll Accounts (ExpressToll Accounts)

- Receive files listing valid ExpressToll accounts

Customer Vehicle License Plate Identification

- Determination of customer vehicle license plate number by review of video images not previously confirmed by OCR

Toll Payment Processing (ExpressToll)

- Interface with third-party ETC payment processing service providers to send valid (ExpressToll) transaction files for payment
- Pre-invoicing check of third-party ETC payment processing service providers valid ETC transponder/license plate number database for license plate number V-Toll match to valid (ExpressToll) transponders/account and subsequent payment
- Accounting for the tolls and fees owed and paid under each toll account

Toll Payment Processing (Image Tolling)

- Acquisition of customer vehicle registered owner contact information with a known license plate number to enable invoicing
- Preparation of toll invoice for post-payment
- Mailing of toll invoices, notices, and other correspondence
- Receipt and processing of customer payments by check
- Receipt and processing of customer payments by debit or credit card
- Accounting for the tolls and fees owed and paid under each toll account

Customer Service

- Respond to customer inquiries and concerns

Customer Interfaces with CDOT

- Website customer interface
- Telephone customer interface including IVR system

External Third-Party Interfaces

- Interface with credit card processing service provider
- Interface for debit transaction processing
- Interface with third-party license plate look-up service providers, including DMV,
- other state DMVs, and/or private look-up service providers

The BOS interfaces with the Toll Transaction Host and external systems, including the CDOT ExpressToll Customer Service Center, CTMC, Colorado Department of Motor Vehicles (DMV), other state DMVs, third-party service providers for payment processing, credit card processing, collections, processing for transactions and/or violations, and other financial and legal services.

10.4.1. Completion of vehicle identification

For some customer vehicles, the toll zone systems may not capture enough data, or the data that were captured were of insufficient quality to permit the vehicle to be positively identified by toll transponder or license plate number at the roadside. A vehicle license plate may have been missing or blocked from view of the video camera by an object such as a cover, trailer hitch ball, etc., or deleterious material such as mud. The license plate may be obscured by unusual lighting or weather conditions, or the video camera may be dysfunctional. The license plate may have an unusual number pattern, font, or color scheme that is difficult to read or unreadable by the automated OCR system, and results in an OCR read confidence level that is below the minimum level required for automated confirmation. In these cases, the toll transaction will not contain a license plate number and will be sent by the BOS VPC or outsourced to a third-party video transaction processing service provider for video image review by a human and completion of the vehicle identification process. If the human process for image review is successful, the license plate number is added to the toll transaction and it is sent on to payment processing. If no license plate number is identifiable, the transaction is posted to a non-collectable account.

Current technology for "video fingerprinting" could be used if allowed to match a vehicle to previous confirmed video images for which the vehicle identity is known. Video fingerprinting is a technology that has proven to be effective at identifying and comparing digital video data. It is a technique in which software identifies characteristic components of a vehicle's image in addition to its license plate number, enabling processing of subsequent images to achieve a higher confidence and accuracy rate. This would, however, require the ability for the back office to store these video data for an extended period of time.

10.4.2. Payment processing

Completed toll transactions (including those requiring human video image reviews for vehicle identification) are ready for payment processing by the BOS. They are sent via Toll Collection System (TCS)/BOS interface to the BOS for distribution to the appropriate queue for either ETC or video processing.

10.4.2.1. ETC transactions

Toll transactions with valid ExpressToll transponder identification codes are sent to the back office authorized for payment processing.

10.4.2.2. LPT transactions

All video toll transactions with confirmed license plate numbers are first checked against the current list(s) of valid license plate numbers associated with valid ExpressToll transponders. If a match is found for a video transaction license plate number to a valid ETC toll account, the transaction is processed as a Video Toll (V-Toll) and the associated ETC transponder number is added to the V-Toll transaction. V-Toll transactions then are sent to a router and then on to the appropriate ETC payment processing service provider. Such transactions are not intended to be a “normal” method of toll payment for established ETC customers. A limited reasonable number of V-Toll transactions will be permitted for those customers who may have innocently misplaced their transponder, whose transponder battery expired or was defective through no fault of their own.

10.4.2.3. Video toll transactions—post-paid, invoiced

Image toll transactions for which no match is found for the license plate number on the list of valid ETC transponders or a customer-established pre-paid video toll account will be processed for payment by invoice. Before an invoice can be prepared, the identity of the registered owner of the customer’s vehicle and vehicle owner’s contact information must be determined. If permitted by state law, E-470 may elect to maintain a database of license plate numbers and contact information for previously invoiced toll customers (the ability and extent to do this varies state to state based on each state’s individual legislation). If such a database resource exists, the first step would be to check it for a license plate number match to enable an invoice to be prepared without consulting an outside third-party license plate number look-up service provider.

10.5. Management

10.5.1. Accounting

Direct integration or at least automated data transfers should be established to allow for electronic toll accounting information (revenues, etc.) to be transferred to the operating agency’s accounting system. The following are high-level operations requirements that will need to be provided by HPTE, either directly, through agreement with E-470, or through agreement with another toll operator/concessionaire:

- **Account Options:** Electronic toll collection systems require drivers to establish toll accounts that are linked to individual transponders. Drivers are charged as their transponders are read at the tolling points.
- **Payment Options:** Most electronic toll collection accounts are automatically linked to credit or debit cards for the automatic payment of tolls, and this is the preferred option for express lanes. Payment by check is accepted via the mail or at customer service centers.
- **Transponder Account Management:** Transponder account management includes all aspects of ETC account management, including opening and closing accounts, transponder order fulfilment, maintaining transponder inventory, assessing fees and credits, processing customer statements, and notifying customers of account irregularities (such as if their transponder is not reading or if their automatic replenishment payment method is expiring).
- **Violation Processing Management:** Violation processing includes the full life cycle of violations: reviewing system-read license plates, obtaining names and addresses from the DMV, printing and mailing notices, processing payments, reconciling financials, and administering appeals. Performance measures would include accuracy of reviewed images and notices, timeliness of invoicing and payment processing, and timeliness of vehicle owner identification.
- **Customer Service Experience:** The customer service experience means providing excellent service to all customer contacts. This includes service in person, by phone, or by correspondence.

- **Financial Accounting:** Financial accounting will include the processing and reconciliation of all customer payments, fees, and credits and reconciliation of fees and revenues against system transaction records for each toll facility.

10.5.2. Auditing

At a minimum, the auditing system should achieve the following goals:

- Minimize toll revenue variance
- Maximize transponder transaction posting
- Maximize the ability to audit both transponder transactions as well as video transactions and violations
- Minimize leakage (uncollected tolls)
- Identify the issues and items needed for periodic audits, while also defining the process for those audits
- Define the process for the audit of customer service center deposits
- Ensure the chain of custody of monies
- Reconcile the toll collection system to journal entries
- Identify potential system issues in a proactive manner
- Ensure the accuracy of transactions and revenues exchanged with interoperable toll agencies.

As part of the auditing process, the system should provide robust and configurable tolling operations and systems reports to monitor and document performance of the customer services, toll system, and interfaces to other systems.

10.5.3. Allocation of revenues

The system will establish an electronic interface to each participating agency for the exchange of transponder status and toll transaction data according to the Interface Control Document (ICD) that governs the exchange of information. The system will process away accounts (transponders issued by other interoperable tolling agencies) and process transfer of funds for express lanes transponder accounts used on other facilities.

10.6. Data Flows and Interfaces

Typically, the interfacing of the toll collection system operations occurs through three main components: (1) the Tolling Point (Roadside Levels), (2) the Toll Transaction Host (Central Level), and (3) the Toll BOS, CSC, and the BOS VPC. The interfaces and the data flows are depicted in Figure 10.6 and discussed below.

From the Toll Zone (Lane) to the Tolling Point (Roadside)

- **Transaction Data**—Including video images for all Toll vehicles using toll facilities
- **Summary of Transaction Data**—Summary and meta data of transaction information
- **System Status**—Information relating to the functioning status or health of the toll zone (lane) and tolling point (technical shelter) equipment

From the Tolling Point to the Toll Transaction Host

- **Transaction Data**—Including video images for all toll vehicles using the toll facilities
- **Summary of Transaction Data**—Summary and meta data of transaction information
- **System Status**—Information relating to the functioning status or health of the lane and tolling point equipment

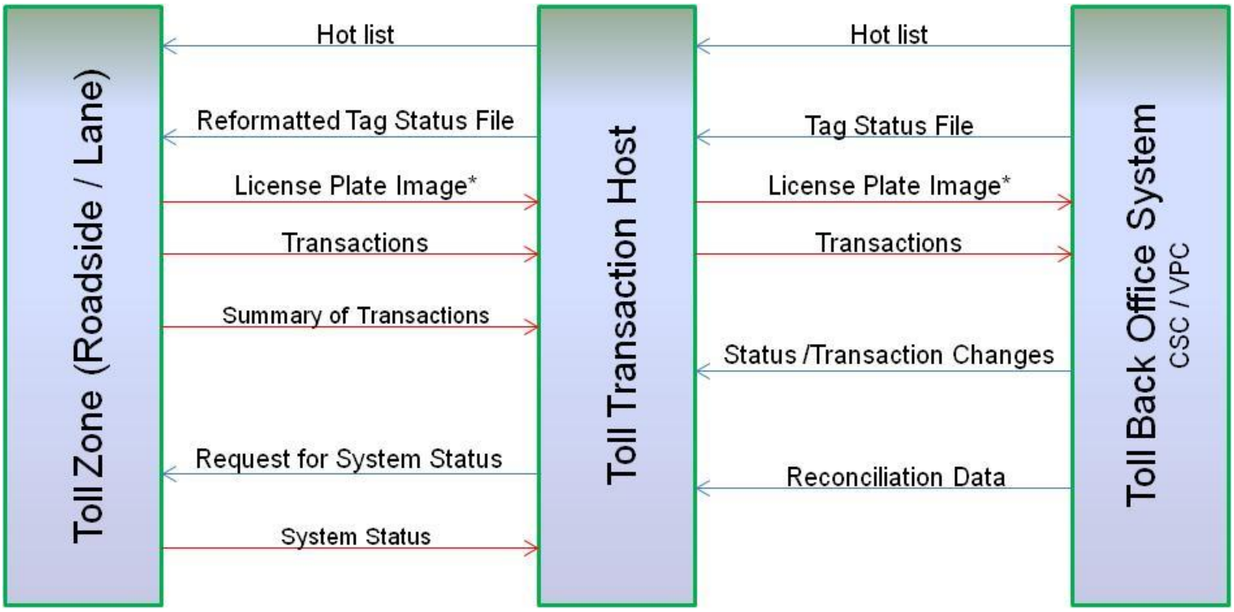


Figure 10.6: Typical Toll Collection Interfaces

From the Toll Transaction Host to Toll BOS CSC/VPC)

- **Transaction**—Transaction data as received from the Tolling Point

From BOS CSC/VPC to the Toll Transaction Host

- **Hot List**—The Hot List consists of license plate data of vehicles of interest including license plates with high unpaid invoice balances and egregious violators
- **Tag Status File**—Denotes the status of all ExpressToll tags
- **Status/Transaction Changes**—Where a license plate has been confirmed by OCR or manually by human image verification, a video toll is posted as a V-Toll, Non-Revenue, or I-Toll, a toll amount was updated, or the classification of a vehicle was changed during video image review.
- **Reconciliation Data**—Includes transaction status, updated transaction information, license plate data (if applicable), and financial information

From the Toll Transaction Host to the Tolling Point

- **Reformatted Tag Status File**—On a regular basis, the Toll Transaction Host will receive the Tag Status Files from the BOS CSC, will format it for use by the toll zone controllers, and will transmit the Reformatted Tag Status File(s) to each toll zone controller via the Tolling Point servers
- **Request for System Status**—The Toll Transaction Host will continuously monitor the systems of the Tolling Point by requesting system status updates
- **Hot List**—A list consisting of license plate data of interest including license plates with high unpaid invoice balances and egregious violators

From the Tolling Point to the Toll Zone

- **Reformatted Tag Status File**—On a regular basis, the Toll Transaction Host will receive the Tag Status File(s) from the BOS CSC, will format it for use by the toll zone controllers, and will transmit the Reformatted Tag Status File to each toll zone controller via the Tolling Point servers
- **Request for System Status**—The Toll Transaction Host will continuously monitor the systems of the facility by requesting system status updates
- **Hot List**—A list consisting of license plate data of interest including license plates with high unpaid invoice balances and egregious violators

11. Active Traffic Management System

11.1. System Overview

ATM integrates ITS Technologies and algorithms to react in real-time to changing traffic conditions. One of the primary purposes of ATM systems is to improve traffic safety and vehicular flows on congested freeways. This is achieved by providing the motorists advanced warnings of downstream congestion, incidents, queues, or other traffic information.

11.2. Description of the Proposed System

The ATM system will be used to dynamically manage traffic based on real-time conditions. The system will consist of ATM gantries eastbound and westbound along the length of the I-70 East project area, spaced at approximately half-mile increments.

11.2.1. ATM systems components

The following are the ATM systems components that will disseminate information to motorists:

Lane Use Signals: LUS are specialized VMSs that are aligned over the center of each lane, and will disseminate information specific to that lane to motorists. Figure 11.1 shows example lane Status display messages.

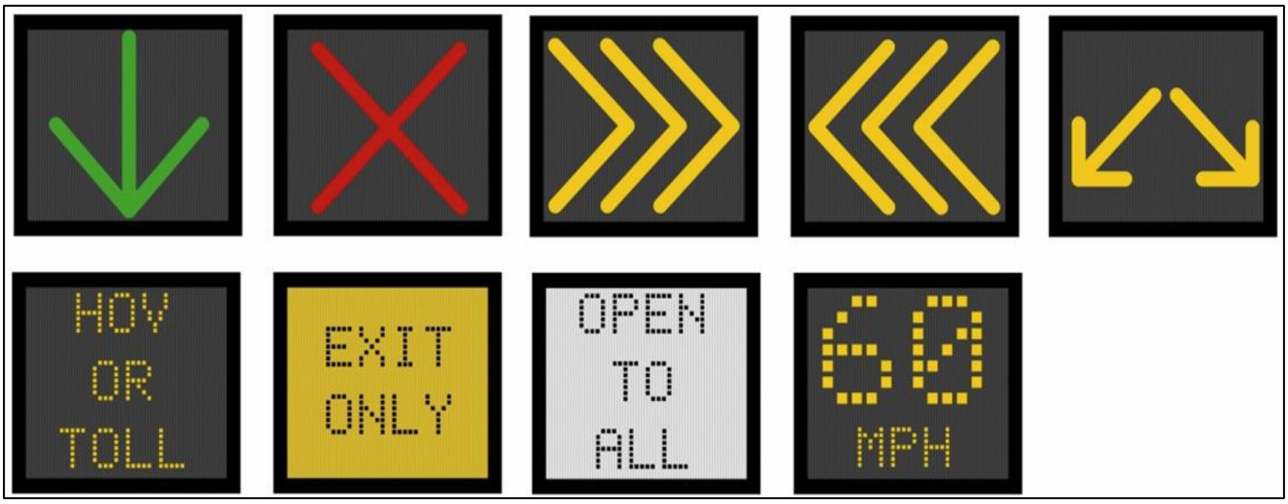


Figure 11.1: LUS Display Examples

Side-Mount Variable Message Signs: The SMVMSs are full-color full-matrix VMSs placed on one or both sides of gantries where there are no full-sized over-head VMS installed. They can be used to post MUTCD-compliant regulatory speed limits or short warning messaging, or to replicate regulatory and warning signs. Figure 11.2 shows some messaging and display options.

Figure 11.2: SMVMS Display Examples

Variable Message Signs: Standard VMSs are mounted above the LUS and used as part of the ATM system to provide more detailed information about traffic conditions ahead. Typically, VMSs measure either 15 feet or 26 feet wide. The width of the VMS will impact the length of messages used on each sign. Figure 11.3 shows a sketch of a standard VMS.

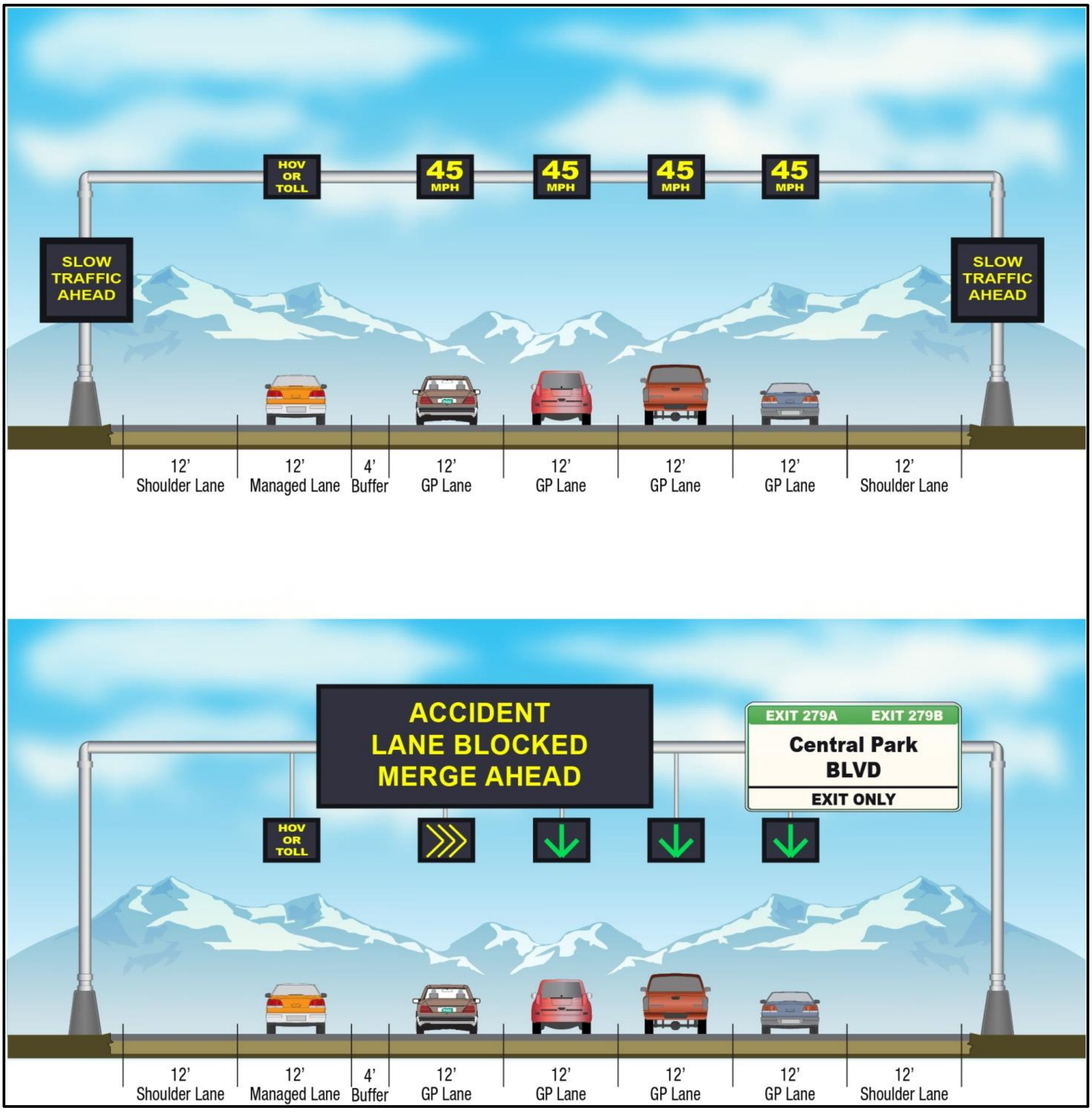


Figure 11.3: ATM Examples for I-70 East TEL's

11.3. Framework within the Existing Regional ITS Architecture

In January 2012, version 7.0 of the national architecture included three service packages to support ATM implementation. These service packages are as follows:

ATMS-22: Variable Speed Limit
ATMS-23: Dynamic Lane Management and Shoulder Use
ATMS-24: Dynamic Roadway Warning

11.3.1. ATMS-22 Variable Speed Limit

This service package will be used to harmonize speeds by creating spatial transition zones between free-flow and congested zones. It is intended to decrease the shock-wave and diminish the propensity of rear-end crashes. The intermediate speed in transition zones is calculated by the VSL algorithm. The system will be monitored and controlled by the CTMC (see Figure 11.4).

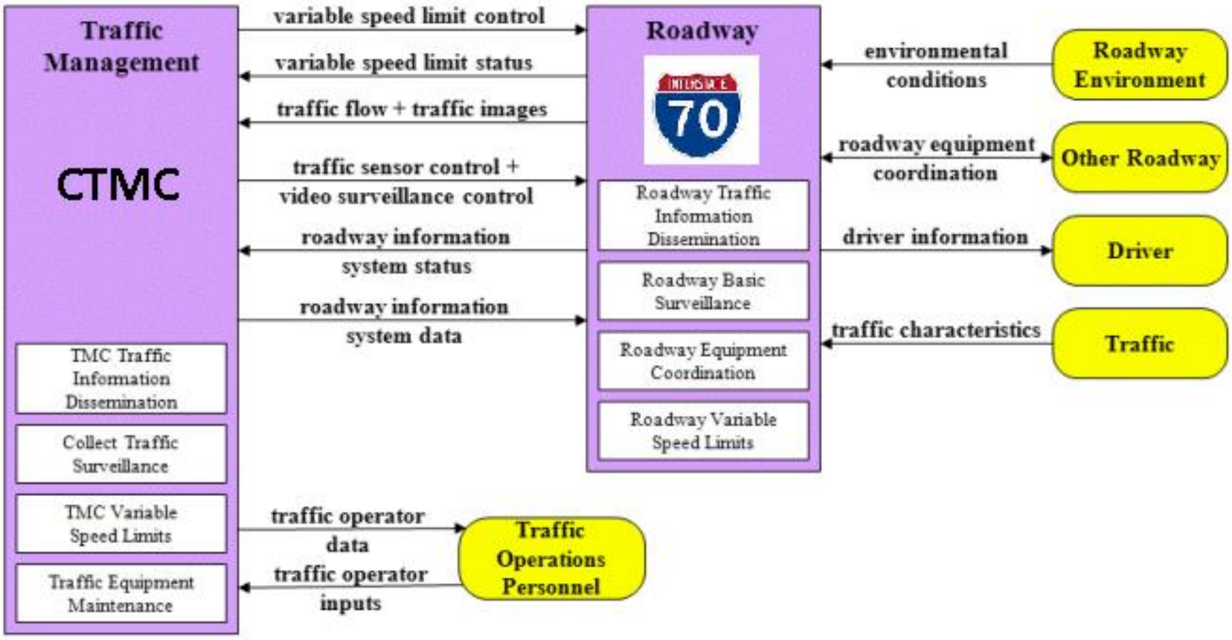


Figure 11.4: ATMS-22 Variable Speed Limit

11.3.2. ATMS-23 Dynamic Lane Management and Shoulder Use

This service package will provide active management of travel lanes (including TEL and GP lanes) along the I-70 East project. This service package will be used in conjunction with ATMS-22 and ATMS-24. The lane management system will be centrally monitored and controlled by the CTMC (see Figure 11.5).

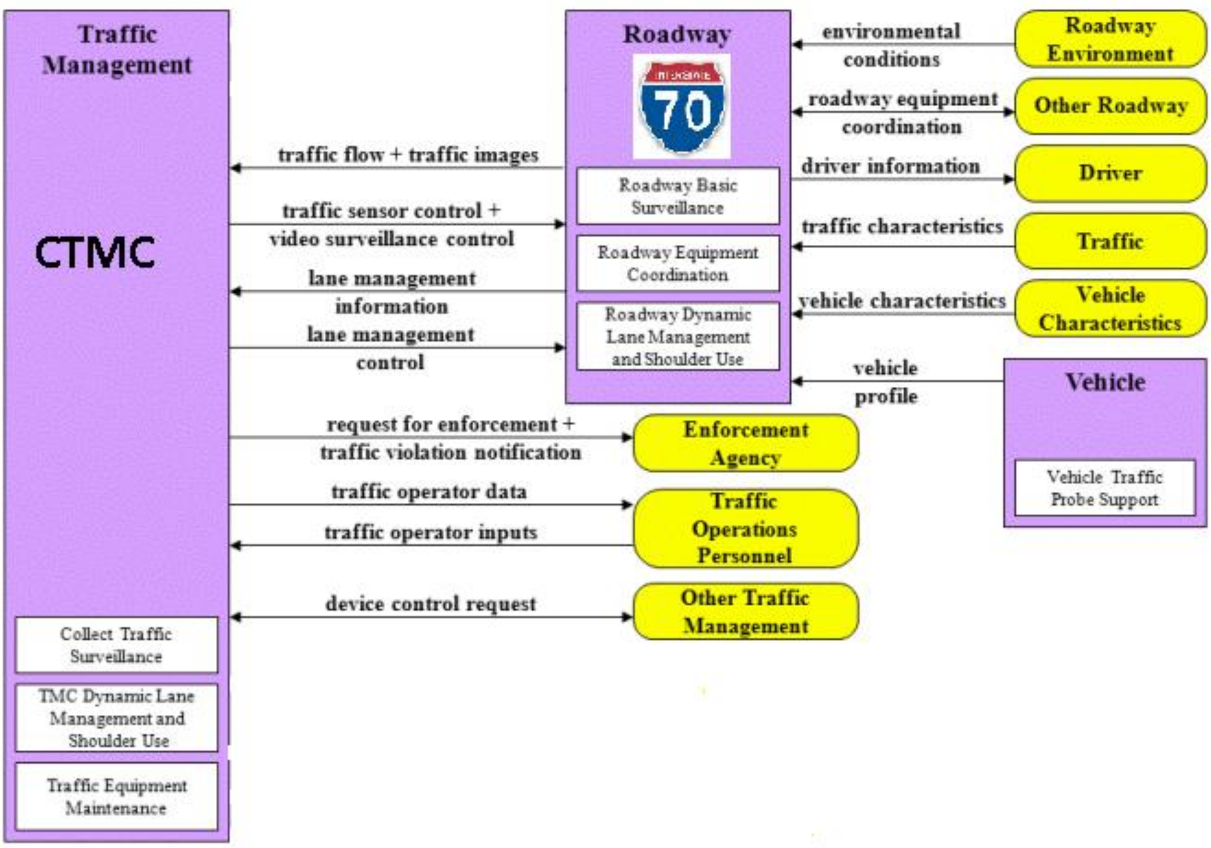


Figure 11.5: ATMS-23 Dynamic Lane Management and Shoulder Use

11.3.3. ATMS-24 Dynamic Roadway Use

This service package dynamically warns motorists on the I-70 East project about approaching hazards. It 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. These dynamic roadway warning systems can alert approaching drivers via warning signs, flashing lights, in-vehicle messages, etc. Such systems can increase the safety of a roadway by reducing the occurrence of incidents. The system can be centrally monitored and controlled by a traffic management center or it can be autonomous.

Speed warnings that consider the limitations of a given vehicle for the geometry of the roadway (e.g., rollover risk for tall vehicles) are not included in this service package but are covered by the ATMS-19—Speed Warning and Enforcement service package (see Figure 11.6).

Roadway warning systems, especially queue warning systems, are an ATM strategy typically used in conjunction with other ATM strategies (such as ATMS-22: Variable Speed Limits and ATMS-23: Dynamic Lane Management and Shoulder Use.

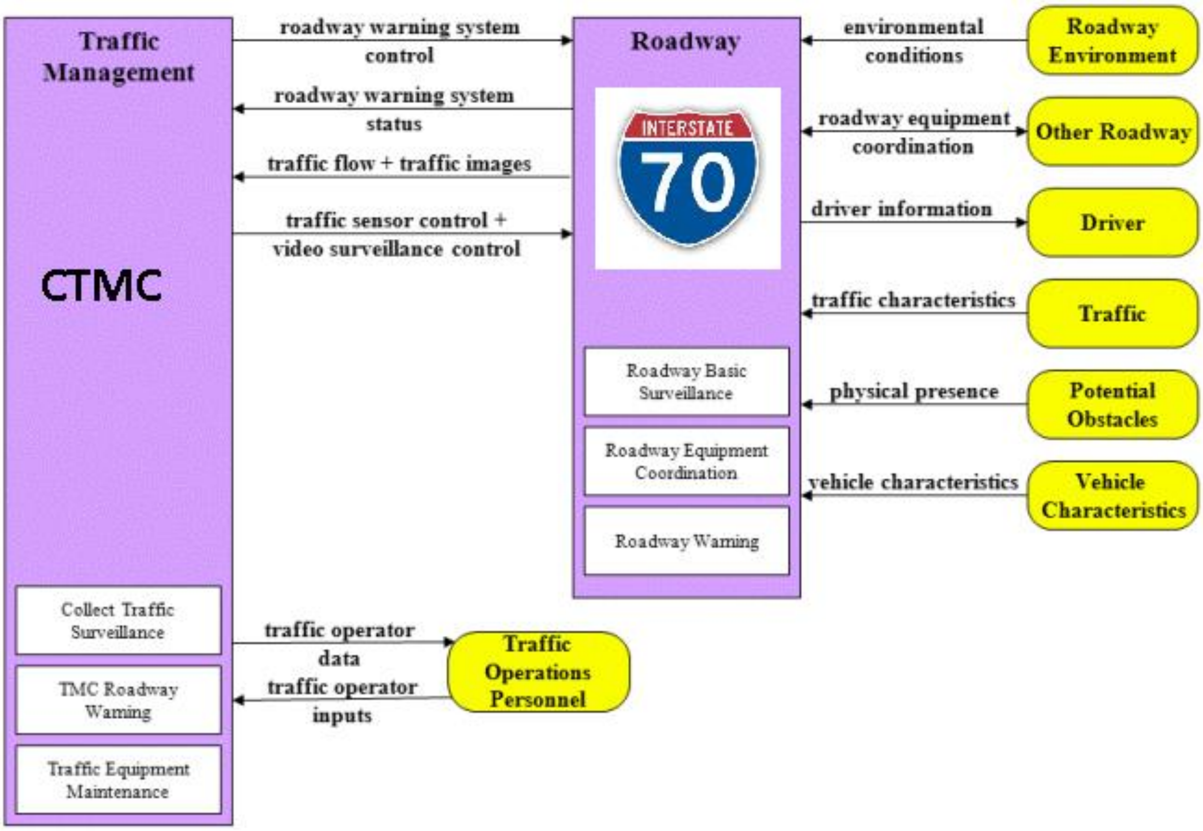
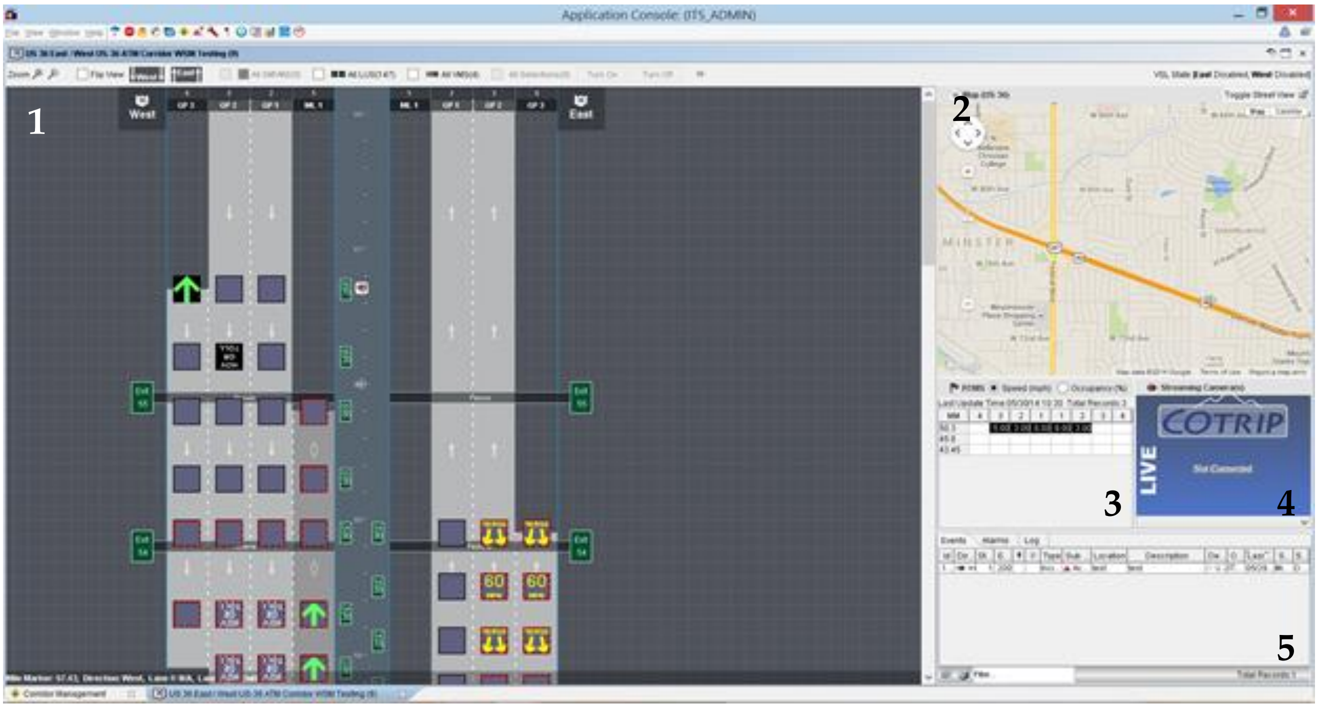


Figure 11.6: ATMS-24 Dynamic Roadway Warning

11.4. Integration with the CTMC

The Colorado Transportation Management System (CTMS) software is the platform through which an operator may manage, view, and control most of the technology elements in use on Colorado roadways. The ATM system for I-25, US 36, and I-70 West PPSL operates within the CTMS software platform and is accessed through the Corridor Management Interface. Figure 11.7 shows a sample of the Corridor Management Screen from the CTMS software Application Console.



1: Graphic Representation of the Corridor, 2: Digital Map, 3: Speed and Occupancy Data Tables, 4: Streaming Camera Display, 5: Tabbed Table of Events, Alarms, and User Logs

Figure 11.7: View Corridor Screen

11.5. Example ATM Operational Scenarios

The following depicts some of the ATM operational scenarios envisioned for I-70 East TEL's:

- Free-flow conditions (see Figure 11.8)
- GP lane blocked (see Figure 11.9)
- TEL blocked (see Figure 11.10)
- Multiple lanes blocked (see Figure 11.11)
- All GP lanes blocked (see Figure 11.12)
- All lanes blocked (see Figure 11.13)
- Severe congestion resulting in a queue (see Figure 11.14)
- Secondary accident (see Figure 11.15)
- Accident cleared (see Figure 11.16)
- Construction zone (see Figure 11.17)

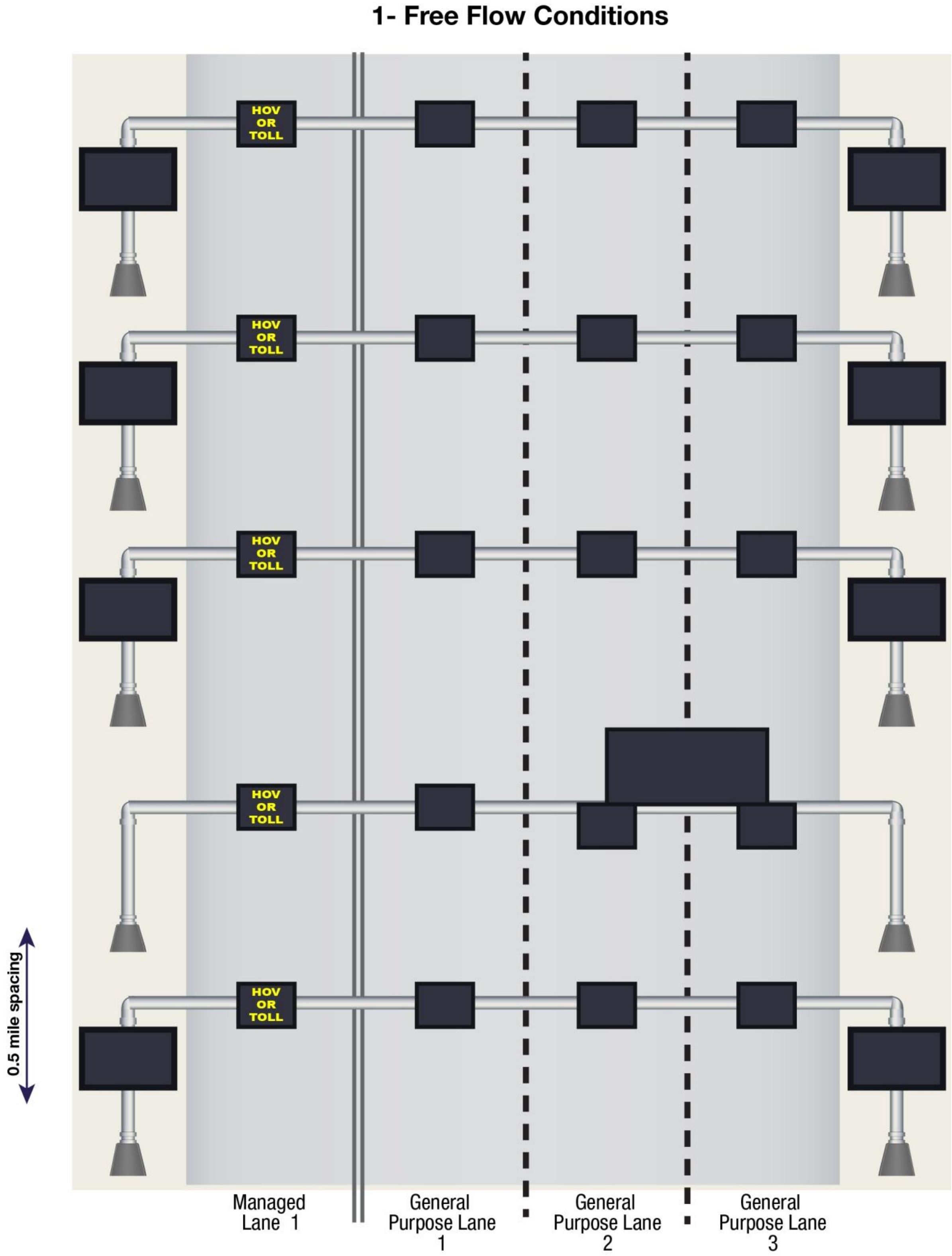


Figure 11.8: Free-Flow Conditions

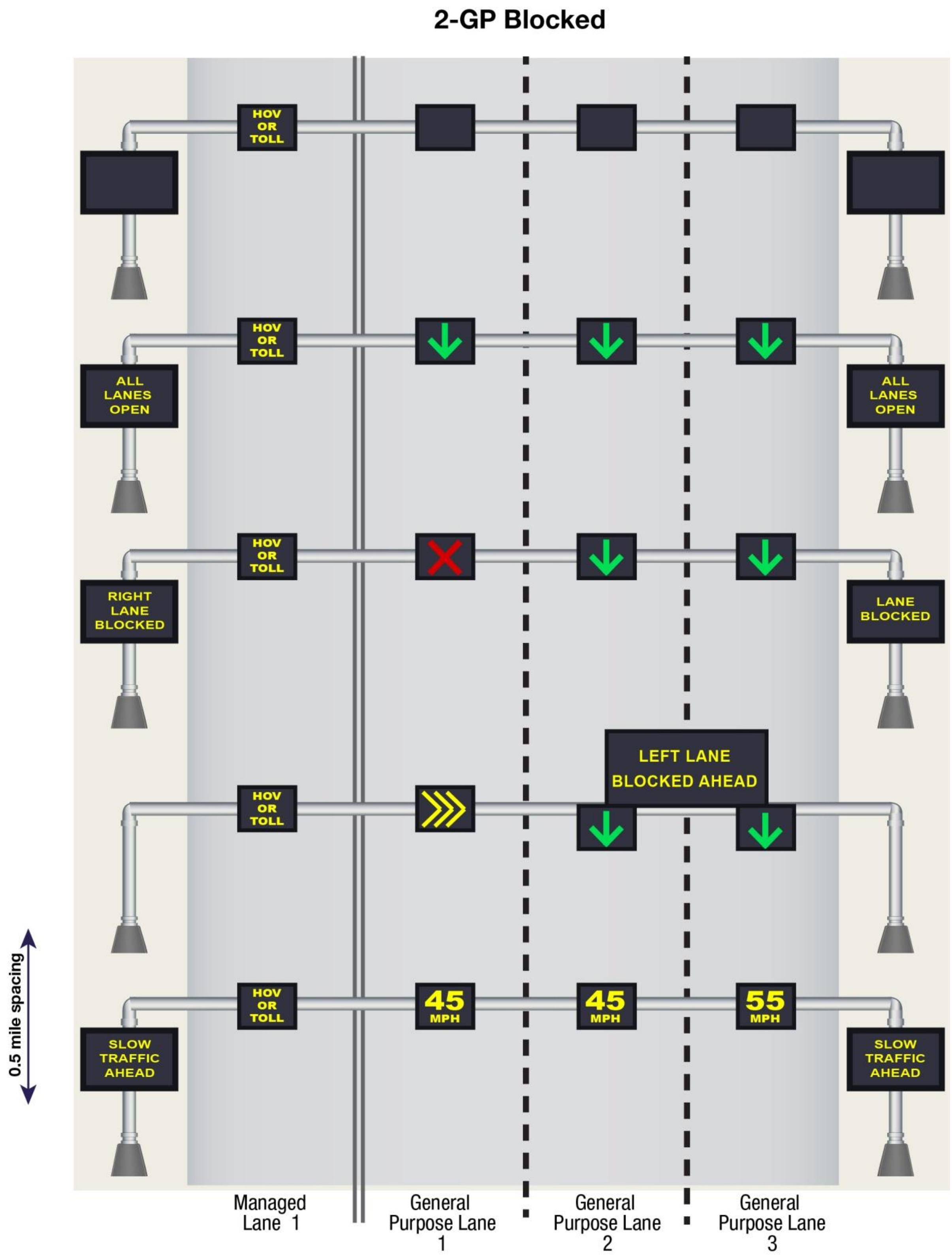


Figure 11.9: GP Lane Blocked

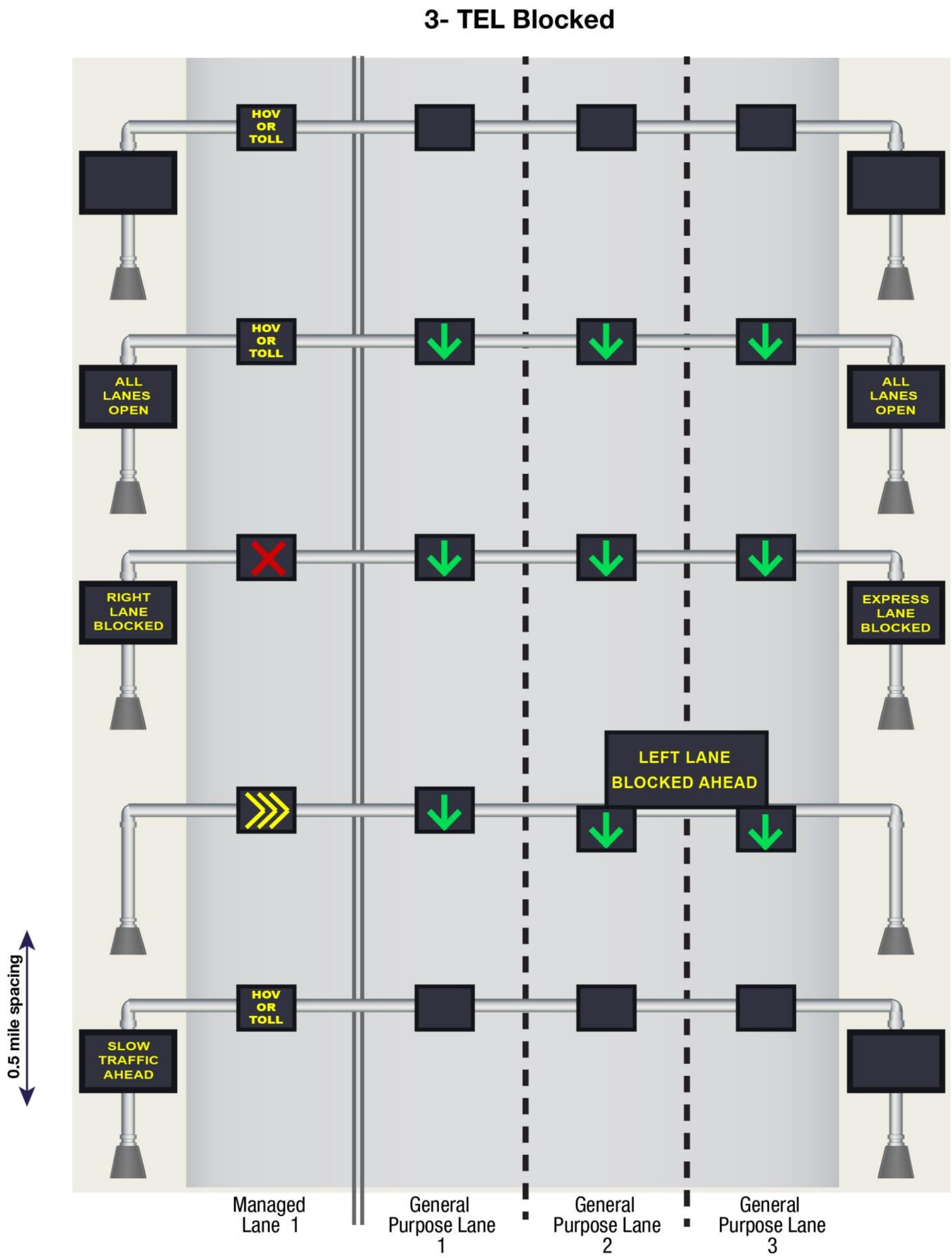


Figure 11.10: TEL Blocked

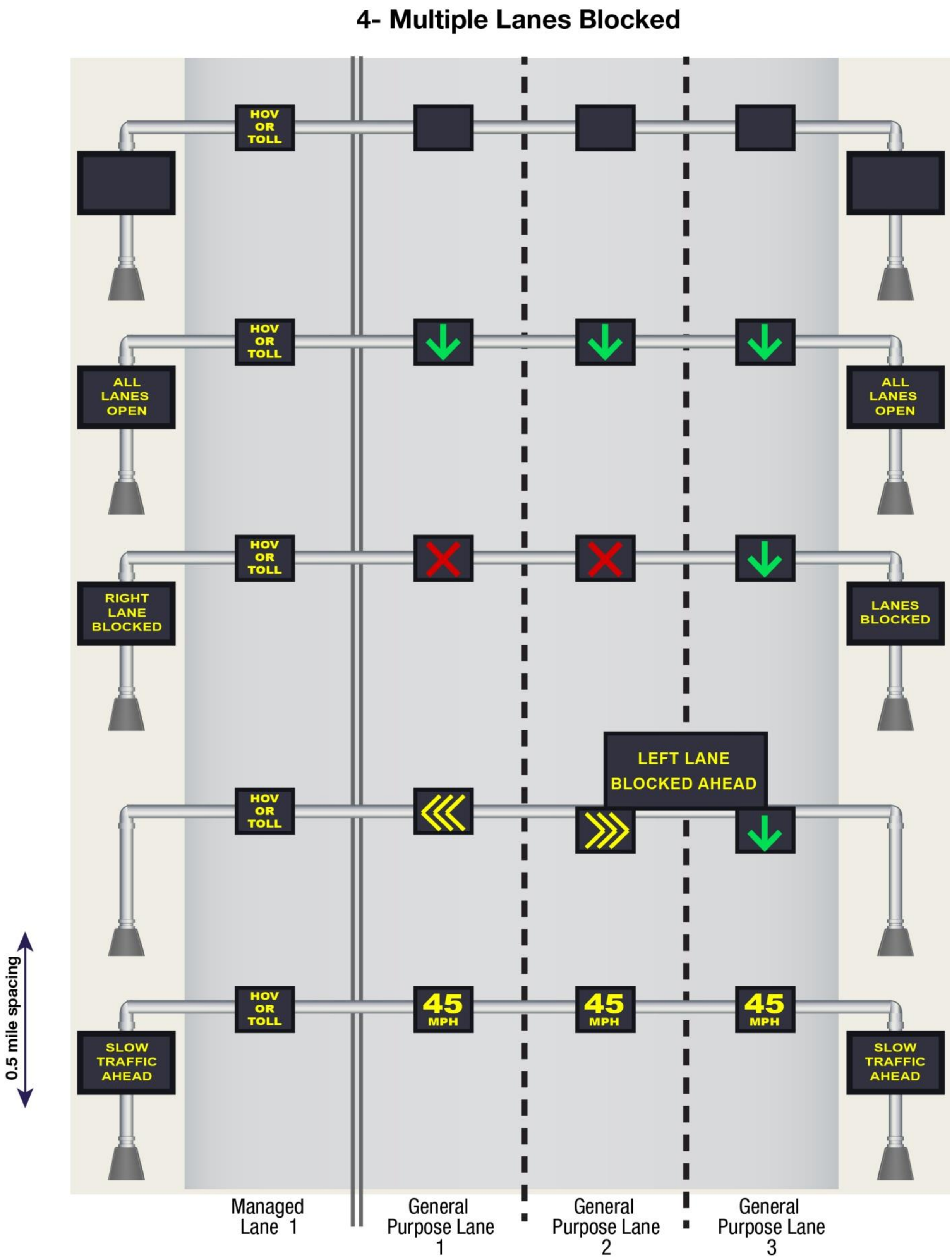


Figure 11.11: Multiple Lanes Blocked

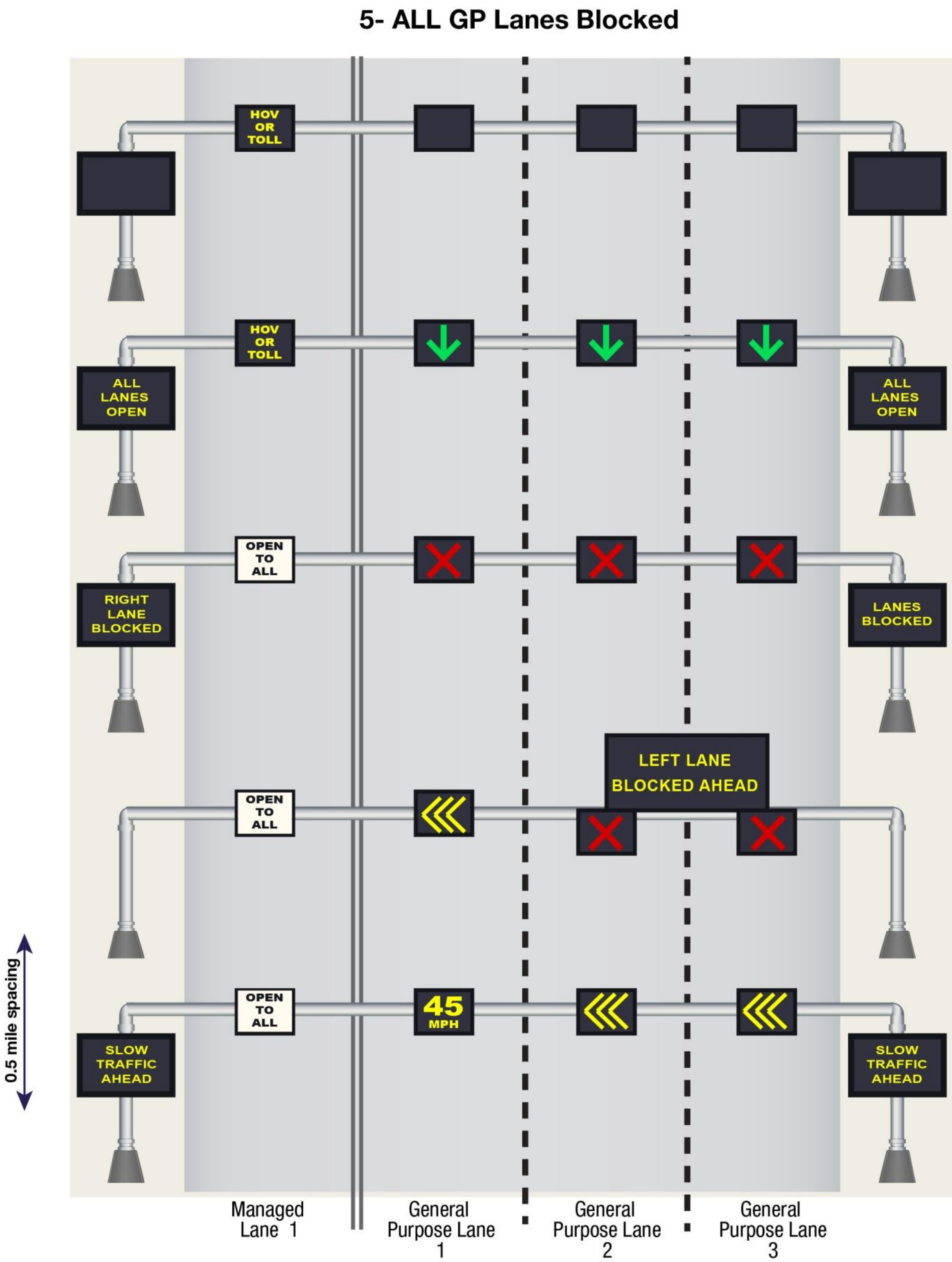


Figure 11.12: All GP Lanes Blocked

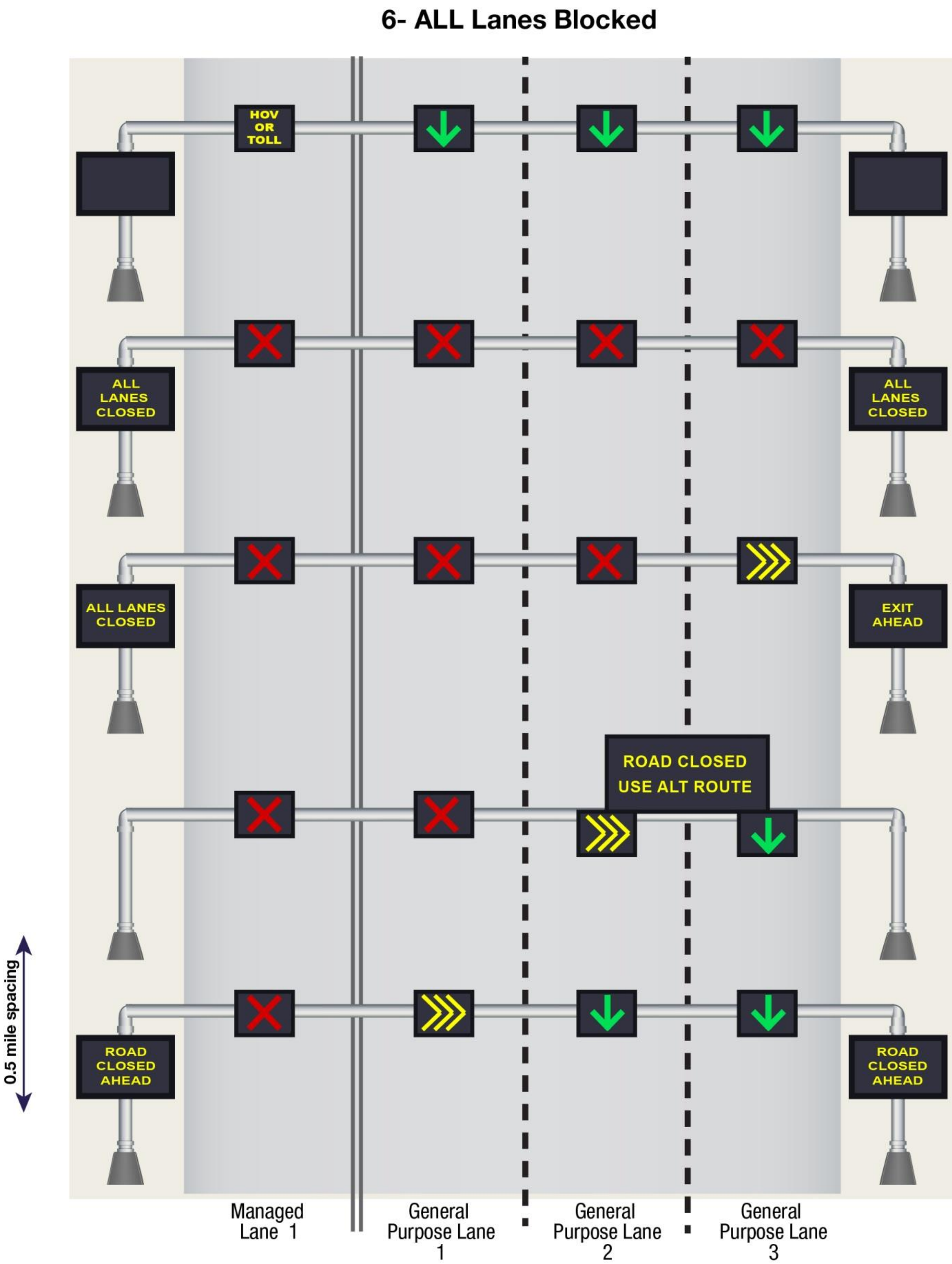


Figure 11.13: All Lanes Blocked

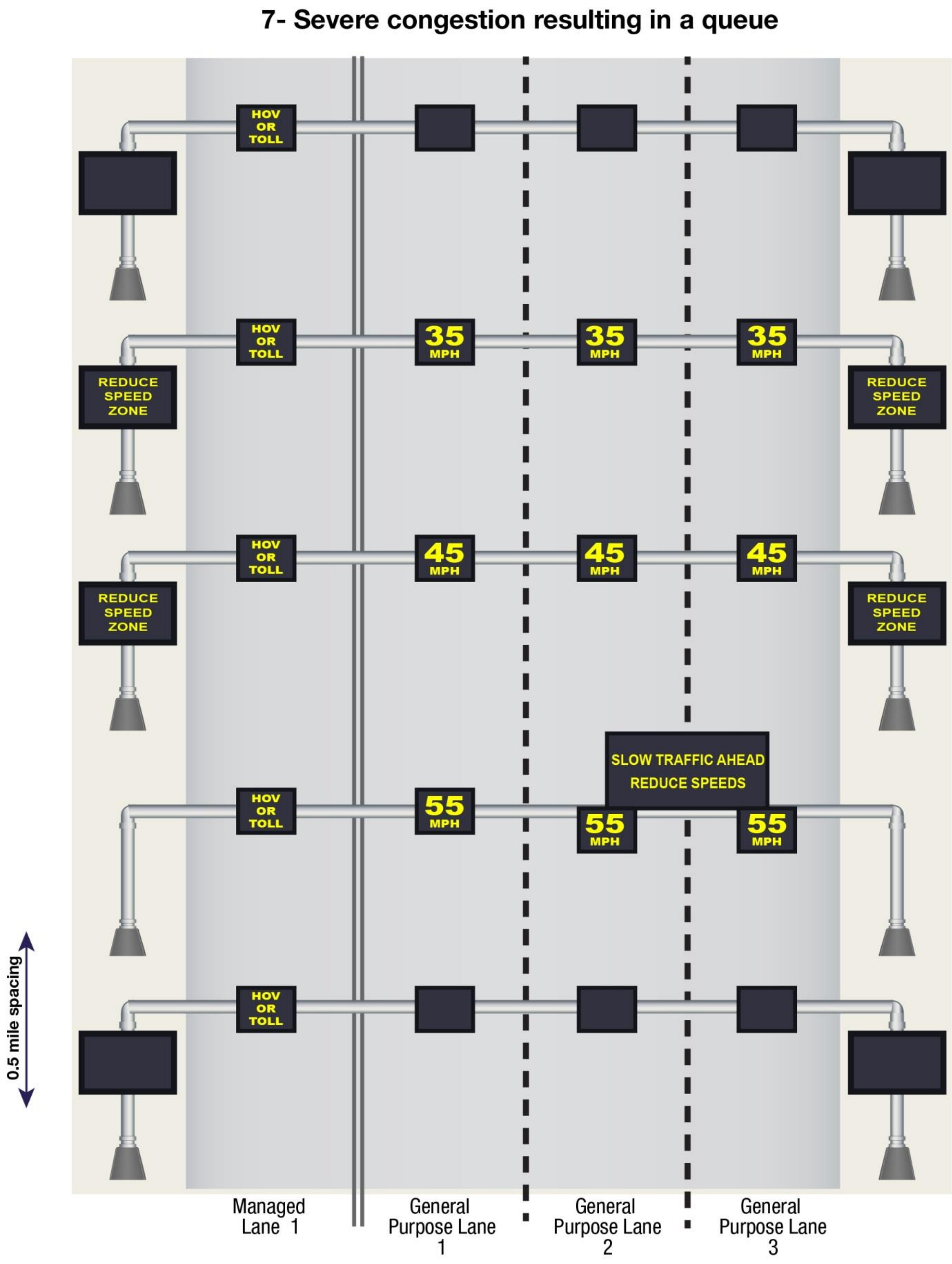


Figure 11.14: Severe Congestion Resulting in Queue

8- Secondary accident

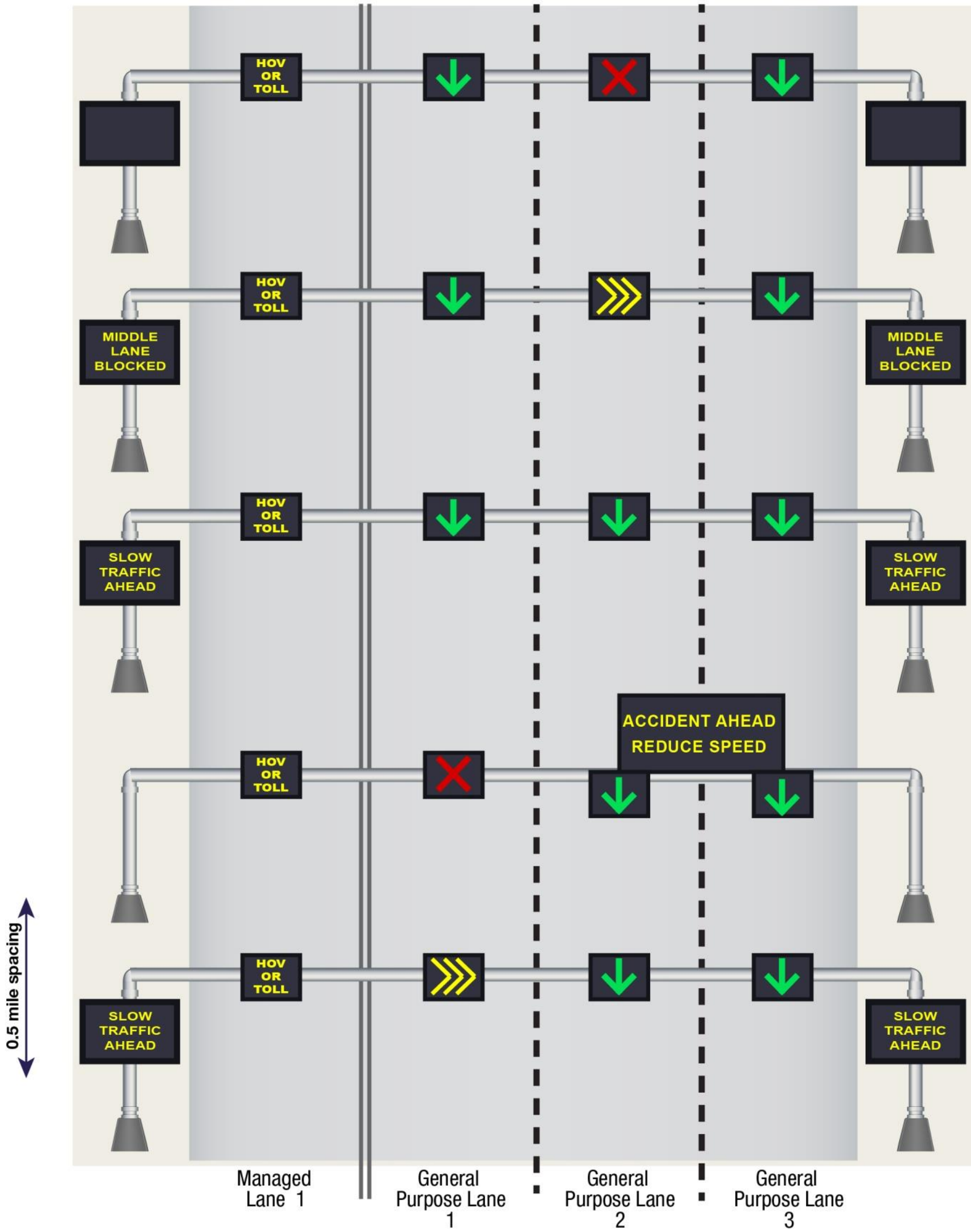


Figure 11.15: Secondary Accident

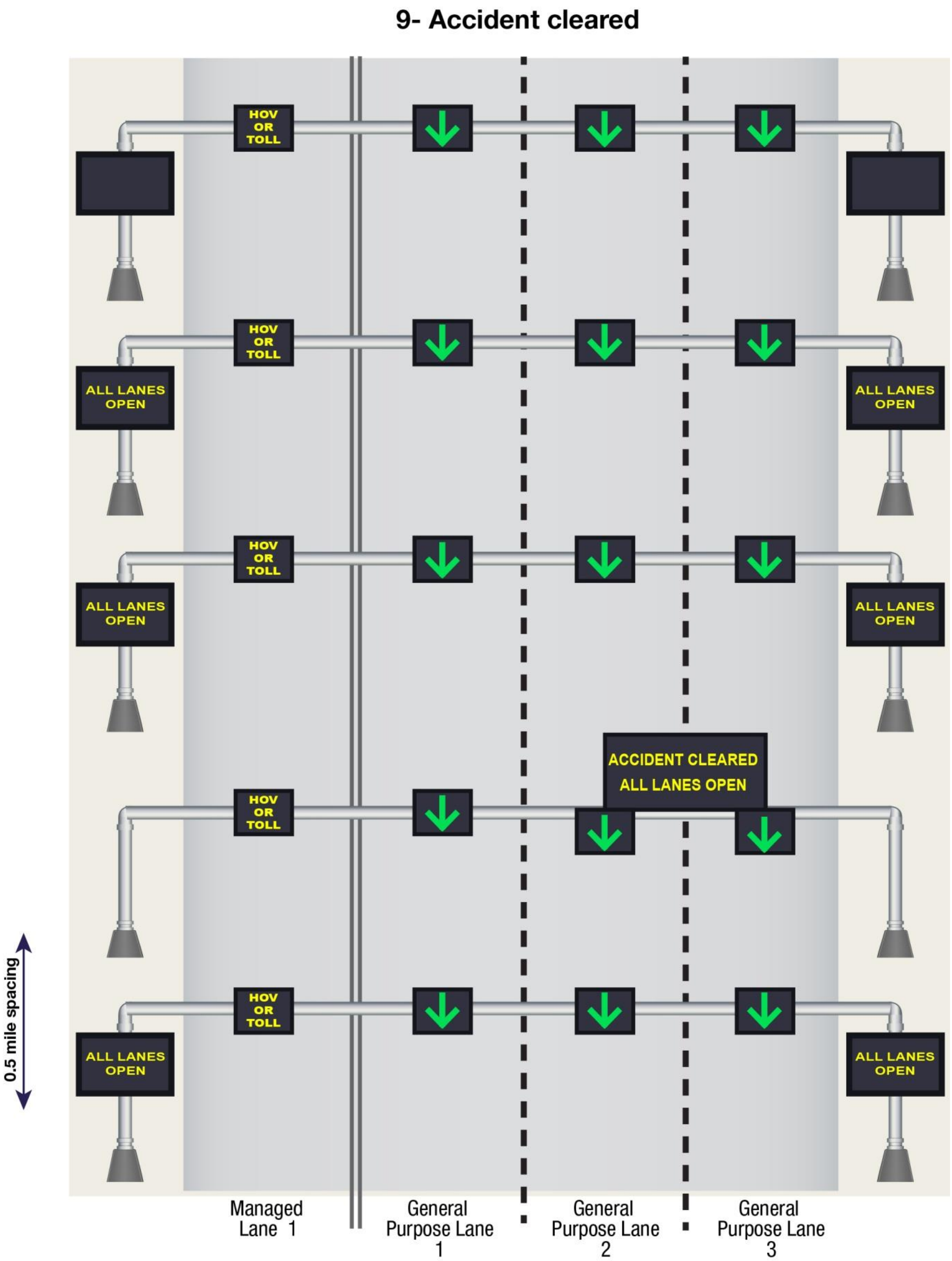


Figure 11.16: Accident Cleared

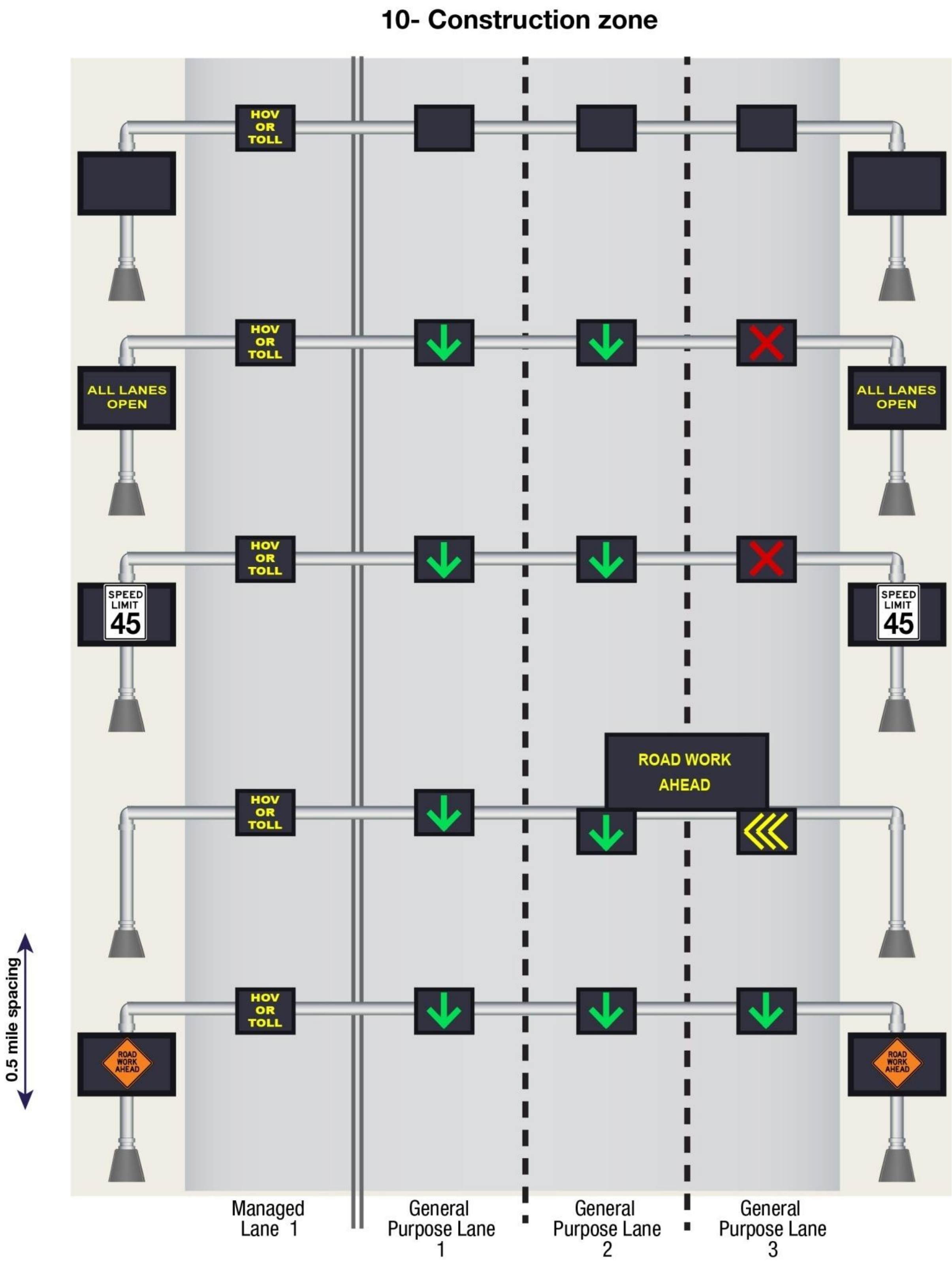


Figure 11.17: Construction Zone

12. System Communication Network

The entire toll collection system and ITS system will be connected by a new 144-strand fiber optic backbone along the full-length of the TEL's for the I-70 East project, as shown in Figure 12.1. The developer will be responsible for allocating the required fiber optic communications and for providing the required civil construction installation for HPTE and civil construction and installation for the ITS equipment. HPTE will install their own equipment, such as cameras, tag readers, collection devices for tolling, etc.

The fiber optic backbone will dedicate a 12-strand buffer tube to the tolling equipment and it will be secured from the ITS network. Both networks will be secured from the public as per each agencies' security policies.

As shown in the figure, the fiber path will incorporate a ring between a new node proposed at I-70 and Airport Boulevard and Node 2, which is located near 70th Avenue and Washington Street (CDOT maintenance facility). The pass-through at Node 1 is only to patch/splice through for fiber connections. The ring will allow both the ITS and tolling to be redundant in the event of a system failure, cut, or other incident.

The ITS network will send data back to the CTMC and the ETC network will send data to the E-470 back office located at 6th Avenue and E-470. The proposed node at I-70 and Airport Boulevard will have a backup system and natural gas generator with secured and separated maintenance equipment racks as well as credential requirements for building entry.

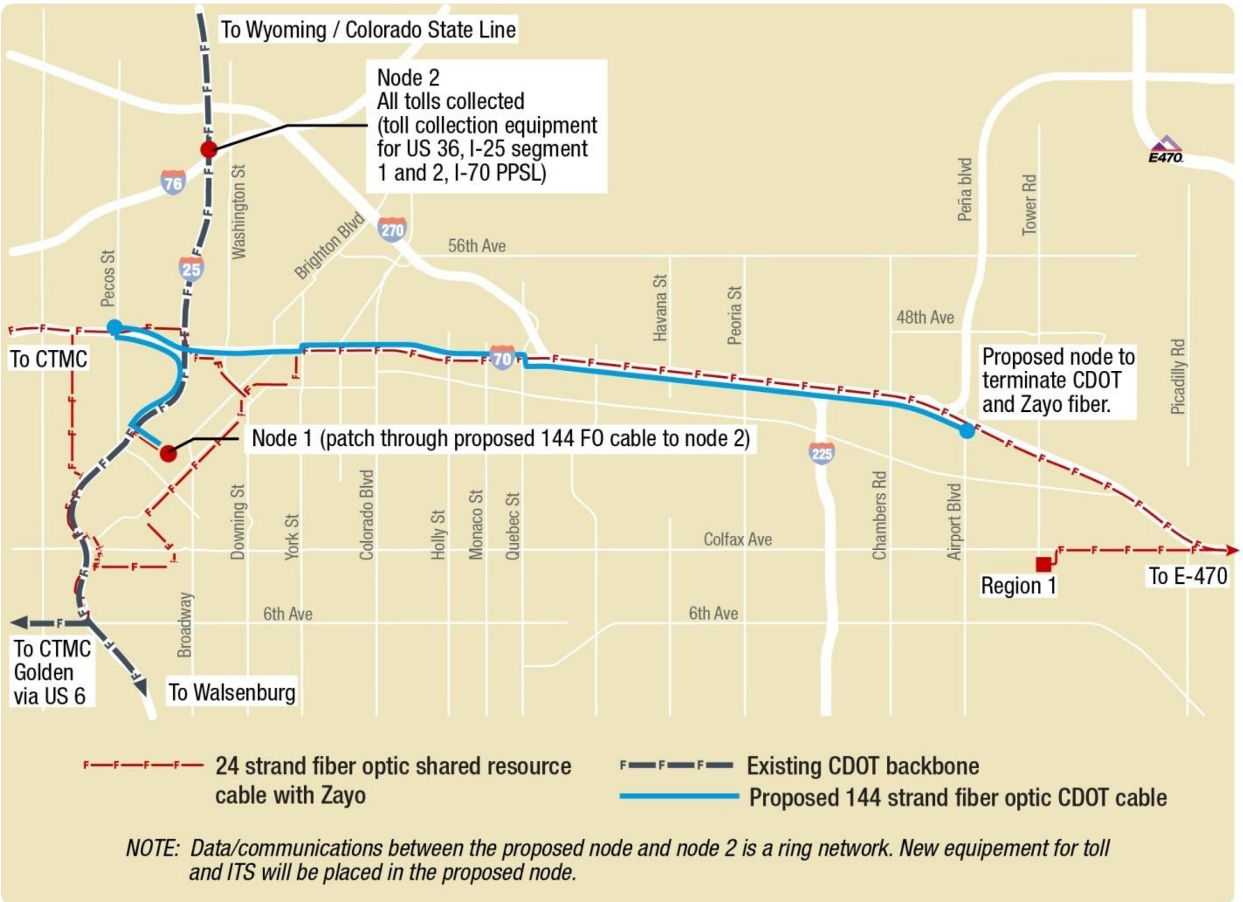


Figure 12.1 Proposed Fiber Optic CDOT Cable

12.1. E470 Network

The ETC devices will be connected to the LAN at the tolling locations and will be the responsibility of HPTE. The communications architecture will support VLAN that allows critical devices to be on their own network—for example, AVI VLAN where the AVI system is connected only to the segment controller.

12.2. The ITS Network

The ITS network will be connected to the CDOT communication equipment and will be the responsibility of the Department. The ITS Network will be used for traffic surveillance, COTRIP. Org, and public information.

13. System Maintenance

Maintenance is an essential element for successful operations of the facility, and will be performed mainly by CDOT, CDOT ITS, and HPTE. With the increase in infrastructure in a project such as this, agencies should prepare staffing plans to quantify these personnel and equipment needs. The following considerations for maintenance should be made during the planning and design phases of the I-70 East project:

Infrastructure Location: Equipment should be located where maintenance personnel can safely access it by setting up traffic control for a shoulder closure. Exceptions include any overhead signs or gantries required to be placed directly above travel lanes. Priority should be given to installation locations that minimize exposure to traffic and the possibility of being struck by an errant vehicle or debris. This includes mounting position on structures, placing equipment out of the traveled way, and installing equipment inside the barrier.

Maintenance Planning: Special attention should be given to the impact of maintenance on the express lanes and the coordination that will have to take place to schedule activities and special closures. These efforts should be documented in the form of a “policy” or “operations” manual. This exercise will assure that routine maintenance procedures can be accomplished safely and effectively without impacting express lanes operations. For example, if a closure is needed in the express lanes, the public needs to be notified and proper traffic control needs to be put in place to prevent drivers from using the express lanes and being tolled for a portion of the facility that may be closed for repair. Such activities would be planned for non-peak periods.

Roadway Maintenance: Roadway maintenance includes removing debris from the roadway, snow plowing, roadway repair, sign repair, striping, and street sweeping.

13.1. Infrastructure Maintenance

With the addition of the express lanes and associated infrastructure, maintenance and operations requirements will increase. The current plans for maintenance roles and responsibilities are as follows:

- The developer will provide for maintenance of lane pavement.
- The developer will provide for maintenance of roadway structures, including bridges, guardrail, median barriers, and similar type equipment
- The developer will provide for maintenance of roadway signage, except for signage installed for express lane operation and toll collection and enforcement. This signage will be the responsibility of HPTE.
- The developer will provide for maintenance and refurbishment of roadway markings on all lanes.

13.2. Traffic Control/ITS

Under contract to HPTE, the operator in charge of tolling will be responsible for hardware, equipment, software, and firmware maintenances for the toll lane systems and equipment installed by the operator. This shall include all traffic control and infield ITS systems installed by the operator in charge of tolling for the purposes of express lane operation, toll collection, and toll enforcement. All other ITS and ATM systems will be maintained by CDOT ITS. All ITS equipment will need to be integrated into the CTMC network.

13.3. Maintenance Program Management

HPTE will be responsible for management of the maintenance program as it pertains to the equipment and systems installed by the operator in charge of tolling. The operator in charge of tolling, assisted by HPTE, will be responsible for coordination with those agencies that have responsibility for maintenance in the corridor that may impact express lane operation.

14. System Effectiveness

The success of the I-70 East TEL's will rely heavily on the ability to monitor operations in real time, efficiently disseminate critical information, and execute appropriate responses.

14.1. Traffic Management Requirements

The efficacy and efficiency of the I-70 East TEL's system will be dependent upon maintaining a high level of reliability for free-flow travel times while not adversely impacting adjacent general-purpose lanes. Without adequate prevention and response measures, degradation on the express lanes will adversely affect customer demand and system revenue. The ability to manage express lanes traffic and operations relies on the ability to monitor system performance and quickly detect and respond to changing traffic conditions throughout the network. Examples of situations that necessitate a need for intervention in a traffic management protocol include:

- Non-recurring events, such as minor incidents and crashes on the express lanes, which can slow or shut down express lane operations in a particular location due to design constraints;
- Non-recurring events on the general-purpose lanes, which will influence speeds and headways or may block accesee to/from the TEL, and may create shock demand for the express lanes' limited capacity; and
- Events of any kind on or nearby corridors that likewise shift demand in unpredictable ways.

A clearly defined set of operational goals will be established for the express LInes that will form the basis for a performance monitoring program. The attainment of these goals should be quantified using various performance measures. The establishment of performance measures will ensure that express lane operations are ideally managed in response to varying traffic conditions. The performance measures also will drive the monitoring and associated data collection that are necessary to ensure adherence to goals. Possible goals and performance measures that may be applied for express lane operations are presented in Table 14.1. A data collection and reporting plan will be developed to detail the data collection and performance reporting needs.

Table 14.1: TEL Goals and Performance Measures

GOAL	POSSIBLE PERFORMANCE MEASURES
Improve Mobility	• Average speeds • Person or vehicular throughput • Average travel times • Rates of violation
Increase Reliability	• Speed or travel-time variation • Transit "on time" performance • Incident clearance times
Improve Safety	• Number of incidents by type • Incident response times
Decrease Environmental Impacts	• Vehicle miles traveled • Fuel consumption • Quantities of exhaust pollutants

GOAL	POSSIBLE PERFORMANCE MEASURES
Preserve Revenue	• Gross and net revenue generation • Operations costs • Revenue leakage • Refunds for customer service • Refunds for diversion into express lanes

14.2. Monitoring Equipment and Data Collection

Monitoring equipment must include sufficient systems to collect and process the necessary data for evaluation of the express lanes' performance. As established in the traffic management chapter, roadway detection devices must be capable of frequently and reliably collecting speed, volume, and video imagery throughout the network. Speed and volume characteristics will be used to evaluate whether operating conditions on the express lanes are within desirable ranges and inform operators whether toll or other operating policies need to be modified to ensure optimal performance.

14.3. Responsible Parties

Data collected by monitoring equipment will provide operational characteristics for discrete points along the I-70 East TEL's. This point detection data will need to be aggregated to obtain a perspective of corridor and network performance. Compiling, reporting, and archiving functions can be conducted by either the express lanes operator or through the CTMC, which reports traffic information to the public. However, there also will be a need for dedicated personnel to oversee and coordinate express lanes monitoring operations. In addition to incident detection, manual monitoring efforts will be required to ensure data quality, oversee the management of monitoring systems, and evaluate trends in express lane operations.

15. Deployment

The initial deployment of the system will be a critical component of the I-70 East project. Close coordination between CDOT, HPTE, the design/build team, and the tolling operator will be necessary to ensure each component of the system is installed and deployed correctly. Thorough testing will need to be performed to ensure that all components of the system are operating correctly before the express lane is open to the public. After the facility is open to the public, the following items should be considered to ensure proper and effective use of the express lane system:

Public Relations and Education: Typically, a public relations and education campaign will need to be carefully developed and implemented prior to and during the initial deployment of the facility to ensure potential users understand how to properly use the facility. This could involve broadcast and print media, online information, special mailings to existing I-25 Express Lanes customers and E-470 transponder holders, as well as a wide variety of targeted strategies to reach people in the communities most likely to use the facility. Also, E-470 Customer Service Center personnel will need to be specifically staffed and trained to deal with these start-up issues (Media blitz, tag ordering and distribution plan, etc.).

Temporary Signage: Supplemental signage should be provided for a limited duration following the initial deployment of the express lane system to assist drivers in correctly using the facility. These signs should provide additional information regarding the location and proper use of the ingress/egress zones, the type of users that may utilize the system, transponder requirements, means by which tolls will be collected, and details on the types of violations that will be enforced and their respective fines. Some of this supplemental signage should be removed after a certain period when users have had sufficient time to learn how to use the facility.

Enforcement: Based on the experience of other express lane facilities in the country, violations rates tend to be highest when facilities are first open to the public. To counter this, enforcement of the express lane should be increased for an initial period to discourage toll and buffer violations and send a clear message to potential violators that enforcement will be a key strategy in the operations of the facility.

Grace Period: It is likely that some exempt users will inadvertently be tolled due to their not being familiar with the proper use of the facility. As a result, a grace period should be considered, but not advertised, during which tolls due to incorrect usage are waived or refunded. This would pertain primarily to HOV users who do not have transponders or do not pre-register and are therefore assessed a toll. These users might have their tolls waived for their first offense if they obtain switchable transponders or pre-register their license plates so as to avoid tolls in the future.