

DENVER METRO AREA
ACTIVE TRAFFIC MANAGEMENT
FEASIBILITY STUDY

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I. INTRODUCTION

Due to continually increasing funding limitations, governmental agencies and municipalities have looked for alternative treatments to mitigate traffic congestion and delay. The intent of these alternative treatments is to maximize the capacity of the existing roadway infrastructure by better managing traffic with focused and cost effective improvements. Also known as Active Traffic Management (ATM), these treatments generally involve additional signing, striping and/or the utilization of existing shoulders to maximize and provide additional capacity to already congested roadways. ATM treatments have been effectively implemented throughout Europe and are just now beginning to be implemented in several states in the United States. Some of the more common ATM treatments include:

- Hard Shoulder Running
- Speed Harmonization
- Queue Warning
- Dynamic Signing and Re-routing
- Junction Control
- Traveler Information
- Ramp Metering
- Incident Response
- Pricing
- And, Managed Lanes

The Colorado Department of Transportation (CDOT) – Region 6 currently utilizes several of these treatments such as ramp metering but intends to expand the application of ATM treatments in order to fully optimize the capacity of the existing freeway system throughout the Denver Metropolitan area.

The purpose of this feasibility study is to provide information on the various ATM treatments in use throughout the US and the world. In addition, based on a set of ATM treatment selection criteria developed for this report and existing freeway geometric conditions, the goal of this study is to provide guidance about the feasibility of the various ATM treatments that are not currently in use. In the future, the results of this study could be used to prioritize the implementation of ATM treatments and help to coordinate the installation of the needed equipment with other construction and highway resurfacing projects.

Some of the other documents and reports that were reviewed or utilized in the development of this feasibility study and should be reviewed prior to implementation of ATM treatments include:

- *Freeway Bottleneck Location in the Denver Region* (Denver Regional Council of Governments, August 2009)
- *2009 Annual Report on Traffic Congestion in the Denver Region* (DRCOG, May 2010)
- *CDOT Region 6 ITS Implementation Plan* (CDOT / Navjoy, June 2009)
- *Regional Intelligent Transportation Systems Architecture for the Denver Regional Area* (URS, November 2007)

II. ATM LITERATURE REVIEW

Much research has been completed with regard to the implementation and operation of ATM systems within the United States and throughout the world. This section provides a summary of the literature review completed of recent ATM reports and articles. The documents reviewed as part of this effort include:

- *Active Traffic Management: The Next Steps in Congestion Management* (American Trade Initiatives, July 2007)
- *Synthesis of Active Traffic Management Experiences in Europe and the United States* (Parsons Brinckerhoff, May 2010)
- *Implementing Active Traffic Management Strategies in the US* (University of Alabama Department of Civil Engineering, October 2009)
- *Active Traffic Management (ATM) Feasibility Study* (PB Americas, November 2007)
- *Efficient Use of Highway Capacity Summary* (Texas Transportation Institute, May 2010)
- *Metropolitan Highway System Investment Study Evaluation of Active Traffic Management Strategies* (Parsons Brinckerhoff, April 2010)

A. Definition of Active Traffic Management and Possible Techniques

Active traffic management is defined as the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing traffic conditions. Focusing on trip reliability, it maximizes the effectiveness and efficiency of the facility. It increases throughput and safety through the use of integrated systems with new technology, including the automation of dynamic deployment to quickly optimize performance. This reduces the delay that occurs when operators must deploy operational strategies manually. Congestion is managed by applying a combination of operational strategies that, when implemented in concert, fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public (American Trade Initiatives, July 2007). Techniques that have been developed both in Europe and the United States include:

- **Temporary shoulder use (Hard shoulder running)** – Use the roadway shoulders, either inside or outside, as a travel lane during congested periods to add capacity and help alleviate congestion related to bottlenecks or an incident on the highway. This could be implemented in the Denver area along freeway segments that have sufficient shoulder width.
- **Speed harmonization / lane control** – Uses speed and lane control signs to dynamically and automatically reduce speed limits in areas of congestion to maintain traffic flow. This can reduce collision risks due to speed differentials related to queuing and congestion. It can also improve travel times due to better traffic flows. This could be implemented along freeway corridors in the Denver area where there is a known speed differential problem during congested periods.

- **Queue warning** – Uses either side mount or over lane signs to warn motorists of downstream congestion and queuing in order to direct through traffic to alternate lanes which helps to utilize available road capacity and reduce the collision risks related to queuing. This could be implemented in the Denver area along freeway segments that tend toward imbalanced use of existing lanes.
- **Dynamic Signing and Re-routing** – Changes major destination signing to account for downstream traffic conditions within the roadway network. This is in use to some extent in Denver area already but could be expanded through use of existing and new variable message signs to direct traffic to other routes during congested periods.
- **Junction control** – Uses lane use control, variable traffic signs and dynamic pavement markings to direct traffic to specific lanes within an interchange area based on demand. This could be implemented in the Denver area in conjunction with other ATM techniques, such as hard shoulder running, to provide additional capacity prior to, after and through an interchange area. However, due to the traffic volume requirements and complex lane configurations needed for junction control, this treatment may be difficult to implement in the Denver area.
- **Traveler information** – Provides travel time information and other roadway / system condition reports either pre-trip or in-route to help travelers make better route decisions. Currently in use in Denver area through Cotrip website and variable message signs.
- **Ramp metering** – Controls the flow of vehicles entering the travel stream to help improve merging efficiency and reduce collisions. It is already in use throughout the Denver metropolitan area.
- **Incident response** – Continuously monitors the roadway network for incidents in order to provide a quick and efficient response that will help remove the incident from traffic and reduce congestion and secondary collisions. One example already in place in the Denver area is the Courtesy Patrol.
- **Pricing** – Manages traffic demand and flow by using priced lane facilities that monitor real time demand and, based on that demand, vary the toll amount collected. This currently in use along I-25 throughout central Denver.
- **Managed lanes** – Involves controlled use of lanes by vehicle eligibility (carpools / transit), access control and price. High occupancy vehicle (HOV) and High occupancy toll (HOT) lanes are currently in use in several locations in the Denver area.

Many of these techniques can and should be use in concert with one another in order to provide the best operations possible. The following table (Parsons Brinckerhoff, May 2010) shows which techniques complement and support other ATM techniques.

Table 1. ATM Complementary and Supporting Techniques

	Complementary and/or Supporting Techniques	Speed harmonization	Queue Warning	Hard Shoulder Running	Junction Control	Dynamic Re-Routing	Ramp Metering	Traveler Information	Incident Response
Techniques	Speed Harmonization		X	X	X			X	
	Queue Warning	X		X		X	X	X	
	Hard Shoulder Running	X	X		X	X	X	X	X
	Junction Control	X		X		X	X	X	X
	Dynamic Re-Routing		X	X	X			X	
	Ramp Metering		X	X	X			X	
	Traveler Information	X	X	X	X	X	X		X
	Incident Response			X	X			X	

B. Benefits Associated with Active Traffic Management

The benefits that have been seen in European applications of various ATM techniques (American Trade Initiatives, July 2007) include:

- An increase in average throughput for congested periods of 3 to 7 percent
- An increase in overall capacity of 3 to 22 percent
- A decrease in primary incidents of 3 to 30 percent
- A decrease in secondary incidents of 40 to 50 percent
- An overall harmonization of speeds during congested periods
- Decreased headways and more uniform driver behavior
- An increase in trip reliability
- The ability to delay the onset of freeway breakdown

In addition, the following table (American Trade Initiatives, July 2007) provides a summary of the possible benefits that may be seen with the implementation of various ATM techniques:

Table 2. Possible Benefits with Implementation of ATM Techniques

Active Traffic Management Strategy	Potential Benefits												
	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	•		•		•	•	•	•	•	•	•	•	•
Temporary shoulder use	•	•							•	•			
Queue warning			•	•	•	•	•	•	•		•	•	•
Dynamic merge control	•	•	•			•		•	•	•	•	•	•
Construction site management	•	•							•		•	•	•
Dynamic truck restrictions	•	•				•		•	•			•	•
Dynamic rerouting and traveler information	•		•	•				•	•			•	•
Dynamic lane markings	•	•							•				
Automated speed enforcement			•		•	•		•	•			•	•

As both the list from European applications and **Table 2** show, there are a multitude of benefits to traffic operations and traffic safety associated with the implementation of ATM techniques. All of the ATM techniques benefit the roadway network in more than one way and the positive impacts to traffic operations can be substantial when the appropriate method(s) is selected for a given corridor.

C. Successful Implementation of Active Traffic Management Techniques

A key component to successful implementation of ATM from an institutional standpoint is thorough outreach to the public / stakeholders in order to provide information and education on the ATM techniques to be implemented. In addition, coordination with local partners and outreach to elected and appointed officials is critical in order to obtain appropriate funding and approval from local government agencies. Ultimate success of the implementation of these traffic management strategies is based on whether the public perceives an operational improvement that can be attributed to the ATM technique that has been implemented. Countries and states that have implemented ATM treatments (that are not currently utilized by CDOT) either on a limited or widespread basis include Denmark, England, Germany, The Netherlands, California, Massachusetts, Minnesota, Missouri, Texas, Virginia and Washington state.

III. ACTIVE TRAFFIC MANAGEMENT IN COLORADO

A. Current Conditions

A number of ATM treatments have been in place in Colorado for some time. CDOT currently dynamically manages traffic through several strategies; including ramp metering, travel time information, dynamic re-routing, and others as described in this section. Other ATM techniques that have potential for additional benefits to improve traffic safety and operations include speed harmonization, queue warning, and hard shoulder running.

Ramp Metering - Ramp metering has been in use in the Denver Metro Area for 30 years and continues to be a useful ramp junction control tool. CDOT Region 6 has ramp meters on nearly every freeway corridor, along with some that stretch into Region 4. Region 1 has ramp meters in place along the I-70 mountain corridor that operates seasonally during weekends.

All ramp meters in Colorado report the freeway's real-time volume, occupancy, and speed back to the central Colorado Transportation Management Software (CTMS) application at the Colorado Transportation Management Center (CTMC). This data feeds into the travel time algorithm and can also be used to generate congestion alarms, as is being done along US-6 (as discussed in the following Dynamic Re-routing section of this report).

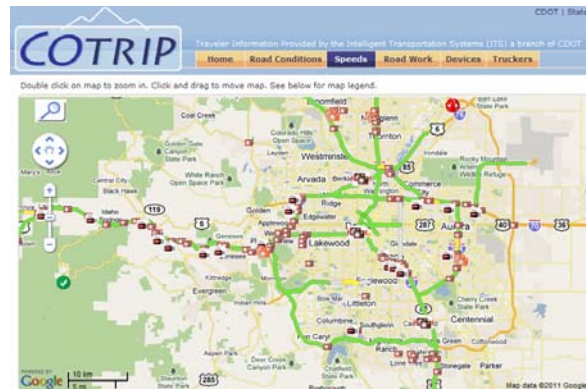


Travel Time - CDOT ITS staff developed a travel time algorithm and has been posting trip travel times along the I-70 mountain corridor for several years. Recently, trip travel times are also being displayed on Variable Message Signs (VMS) along the US 6 and C-470 corridors within Region 6 and along with I-25 south from Denver to Colorado Springs. The travel time algorithm hinges upon data received by a number of ITS devices, including Travel Time Indicators (TTI), Ramp Metering, Microwave Vehicle Radar Detectors (MVRD), and Doppler devices. TTI devices read the Title21 Radio Frequency Identification (RFID) toll tag transponders along corridors to measure segment travel times. This is important to note as the other three devices, Ramp Metering, MVRD, and Doppler, only measure point data to give a snapshot of travel conditions.

These devices are prevalent within Region 6, and travel conditions and travel times are reported on the CDOT website (www.cotrip.org) for many more of the corridors than there are VMSs installed along (see CoTrip image below).



Dynamic Re-routing – Dynamic re-routing provides a means of managing recurrent and non-recurrent congestion. To date, CDOT's efforts in this area have been focused on managing non-recurrent congestion occurring from incidents or other infrequent events. Many of the corridors within Region 6 have incident management plans in place, and CDOT has installed VMSs at key decision points along a given corridor where alternate travel routes may be available.



The US 6 corridor within Lakewood and Denver is a good example of dynamic re-routing. CDOT and the local agencies, with the support of DRCOG, instrumented the corridor with TTIs, MVRDs, and Closed-Circuit Television Cameras (CCTVs). TTI and MVRD devices measure the point and segment travel conditions and report an alarm that appears on the CTMC Operator's console, providing an alert of a potential incident (see image below). In conjunction, local agencies have instrumented the interchanges with Blank-out Signs (BOS) that advise drivers to use the parallel routes of either Alameda Avenue or Colfax Avenue and avoid the US 6 freeway corridor. Special traffic signal timing plans on the parallel routes can be implemented when an incident occurs. This is perhaps a more complex example than typical but is of interest because its development included a multi-agency approach and BOSs were placed to assist motorists with wayfinding.



Queue Warning – When queue warning is mentioned as an ATM treatment, it conjures up thoughts of a corridor-wide approach as described by the research and applications in Europe and, more recently, in Washington State along Interstate 5. Colorado has only recently begun to explore this systematic approach. Currently, Colorado has two queue warning systems operating; one in Region 6 in the urban environment at US 285/Federal Boulevard and the other in Region 1’s mountainous and rural downhill segment along I-70 near Georgetown. The US 285 queue warning system measures queues that spill back from the traffic signal and trigger a BOS. The Georgetown queue warning system measures queues at the bottom of a downgrade and around a horizontal curve to warn drivers of slowed or stopped traffic ahead (see image). Though one of these systems is for an interrupted flow facility and the other is uninterrupted, both seek to reduce the number of back of queue crashes, and they both rely upon accurate and reliable measurements of the congestion. However, these queue warning systems are “spot” treatments and are not part of a corridor-wide approach to dynamically managing traffic.



Variable Speed Limits – A Variable Speed Limit (VSL) system has been installed along I-70 through the mountain corridor and in the western Denver area. The VSLs normally display the posted speed limit but are lowered by 10-mph when chain law is in effect. They are not currently used for speed harmonization and are not tied to any level of congestion. The VSL signs replace all static regulatory speed limit signs within the area they are installed. The Region is also looking into implementation of variable speed limits between Silverthorne and Bakerville.

Managed Lanes – There are several managed lane facilities within CDOT Region 6, including the I-25 EXpress Lanes (a High Occupancy Toll [HOT] lane facility) and segments of US 85 and US 36 (High Occupancy Vehicle [HOV] lanes). There is a project underway to extend the US 36 HOV lanes and convert them to HOT lanes. These managed lane facilities are a mixture of full-time and part-time restricted use, and barrier-separated and buffer-separated lanes. The I-25 EXpress Lanes are variably priced by time-of-day, and it is anticipated that they will be dynamically-priced based upon travel conditions in the foreseeable future. The I-25 EXpress Lanes are a cashless tolling system relying on toll tag transponders and video tolling for payment.

Enforcement – Enforcement for traffic violations is conducted manually along CDOT’s roadways, including the managed lane facilities. On the arterial street network within the jurisdiction of the local agencies, automated enforcement strategies include red light running cameras and speed radar vans. Neither of these automated enforcement strategies is currently in use by CDOT.

Incident Response – Courtesy Patrol for incident response has been in use for many years within Region 6 and has proven to have a very high return on the capital investment. Region 6 has 19 patrols that operate 5.5 hours per weekday during the peak travel periods. Courtesy Patrol is dispatched from the CTMC and provides assistance to disabled vehicles to help get vehicles moving again, clear incidents, and prevent secondary accidents from occurring.



B. CDOT Region 1 ATM Efforts

CDOT Region 1 has been the most proactive in exploring ATM and identifying corridors for implementation, in conjunction with CDOT ITS, DTD Research, and Staff Traffic and Safety. These efforts are building the foundation for many of the underlying principles of ATM and how they will be approached in Colorado.

There are several on-going ATM efforts within Region 1. Region 1 has \$10 million earmarked from the FASTER safety funds to implement ATM along the I-70 mountain corridor; \$5 million in each of the next two fiscal years. There is an ATM demonstration project being designed and slated for construction in CDOT Fiscal Year 2012. This project will install a full-color, full-matrix overhead VMS east of the east portal of the Eisenhower-Johnson Memorial Tunnel. It will alert eastbound traffic of the travel conditions through this geometrically challenging segment of I-70. The VMS will display an advisory speed and warn of congestion ahead. This demo project may be a precursor to a larger, corridor-wide deployment.

Region 1 is also developing a Concept of Operations for the I-70 mountain corridor. The Concept of Operations describes how ATM could be implemented along the corridor, which treatments would comprise the system, and how each of the components will function together. These efforts by Region 1 are developing the “look and feel” of ATM, including device placement, sign layouts and spacing, and the interface with the traveling public. All ATM treatments are being considered as part of the study.

In conjunction with Region 1, CDOT HQ is also undergoing a research effort to calibrate a predictive algorithm to establish speed harmonization. The research findings will be directly applicable to corridors within Region 6. However, it should be noted that the approach and deployment of ATM along the rural, mountainous I-70 corridor may vary with ATM treatments in the urban environment of Region 6. Specifically, congestion along the I-70 mountain corridor is largely compressed to weekends during summer and winter months. Conversely, freeways within the Denver Metro Area experience congestion during all five weekdays throughout the year. The driver demographic is vastly different too, with travel in the mountains largely due to recreational and tourist trips and peak period travel in Region 6 comprised of commuters more familiar with their route. The Denver Metro Area is also not as geometrically constrained by terrain as the mountainous corridor, though it certainly has footprint limits. Furthermore, the nature of the scenery in the urban, built environment within the Denver Metro Area is not as sensitive as in the mountain corridor. Sign structures, devices, and electronic messaging

associated with ATM are generally not as much of a contrast to the surrounding environment as they are in the mountain environment.

C. *Linking ATM to Regional ITS Architecture and Region 6 ITS Implementation Plan*

This section of the study discusses how ATM fits within the context of the *ITS Architecture for the Denver Regional Area* (URS, November 2007) and the *Region 6 ITS Implementation Plan* (CDOT / Navjoy, June 2009). Both of these planning-level documents describe the vision for ITS in the Denver Metro Area and Region 6.

ITS Architecture for the Denver Regional Area

The National ITS Architecture developed and managed by the Federal Highway Administration provides the framework for developing regional ITS architectures. The ITS architecture for the Denver Metro Area follows these Federal guidelines, and requirements in cases where Federal funding is involved for developing and documenting the ITS architecture. The plan describes the ITS approaches, strategies, and functionality either in place or planned for the region. The plan also discusses the regional stakeholders and their respective ITS roles and responsibilities. By nature, this ITS architecture plan is intended to be a “living” document that is meant to have regular updates that reflect advancements and changes in ITS deployments within the region. The introduction of ATM strategies into the region could necessitate an update to the current plan, as ATM may introduce a revision or addition to the use of current market packages and a change in stakeholder roles and responsibilities.

The plan states the following high-level goals for ITS in Colorado. The goals of ATM fundamentally support the goals of the ITS Regional Architecture.

- Improving mobility through maximizing the productivity of the transportation system
- Improving mobility through providing travel choices and increasing travel efficiency
- Increasing safety for the traveling public
- Enhancing intermodal connectivity and inter-jurisdictional coordination

One of the central elements of the Denver Regional ITS Architecture Plan is the identification of ITS Market Packages. There are a number of ITS Market Packages relevant to ATM for CDOT Region 6 and the ITS Branch. These Market Packages are discussed in **Appendix A**.

Region 6 ITS Implementation Plan

This document is an ITS implementation plan for Region 6 that consolidated “all ITS projects for Region 6 into a single document that will enable Region 6 staff (engineers, planners, designers, maintenance personnel, etc.) to manage the planning, programming and deployment of individual ITS projects.”

“This Region 6 ITS Implementation Plan contains all known ITS deployments and/or projects on corridors of significance from the previously mentioned ITS planning documents. This Plan consolidates ITS deployments and/or projects on thirty two (32) corridors of significance in an organized and efficient manner specifically for Region 6.”

This document also contains information about the current ITS conditions within Region 6, including a summary of devices and communications infrastructure. The existing infrastructure is a key component of ATM since any such treatments will require integration of existing ITS devices, such as detection devices, CCTV, HAR, VMS, ramp meters, and CoTrip. Any proposed ATM treatments along corridors should seek to work with the goals of this plan, recognizing that the application of ATM differs more so than the infrastructure and instrumentation. There are commonalities between the ITS plan and potential ATM systems. For instance, a fiber optic communications network is proposed for many of the corridors. This would support the connectivity to ATM field devices. Other ITS elements, such as expanded Courtesy Patrol, additional VMS, CCTVs, and the development of Incident Management Plans, are called for on many of the freeway corridors. All of these elements would work in conjunction with ATM. Region 6 and the ITS Branch have gone through the exercise of determining approximate locations for these devices (e.g., VMS locations). This would be a good starting point for developing preliminary design layouts for ATM treatments.

IV. IDENTIFICATION OF CANDIDATE CORRIDORS

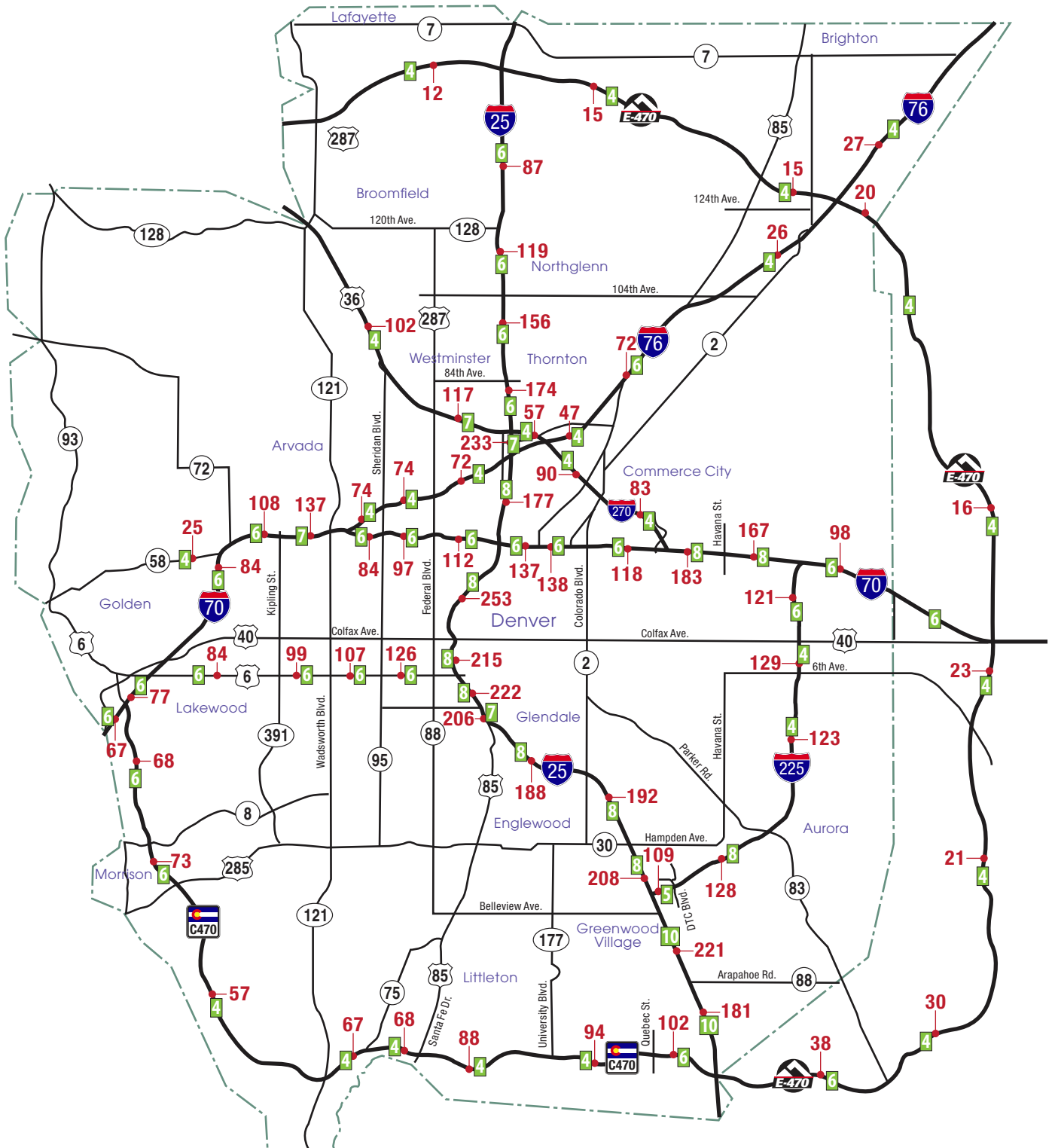
Each of the freeway candidate corridors were defined by first locating congestion on the freeway network through the use of existing traffic counts and the number of mainline through lanes. The existing traffic volumes and number of mainline through lanes can be seen on **Figure 1**. The traffic volumes shown on this figure were divided by the number of lanes to determine a per lane daily traffic volume. A three tiered “congestion index” was then developed based on these per lane daily traffic volumes to determine the most congested, moderately congested and least congested freeways in the Denver area. The results of these calculations and the color coding for the three congestion index tiers can be seen on **Figure 2**. Freeway bottlenecks identified in the Freeway Bottleneck Location in the Denver Region (Denver Regional Council of Governments, August 2009) are also included on this figure. Corridors with a congestion value in the orange or yellow category or with a bottleneck location were identified for further analysis to determine the feasibility of ATM treatments. The major freeway corridors identified for further analysis include the following:

- **US 6** – Kipling Street to I-25
- **I-25** – C-470 to 120th Avenue
- **US 36** – Northwest of Wadsworth Boulevard to I-25
- **I-70** – State Highway 58 to Pena Boulevard
- **I-225** – I-25 to I-70
- **C-470** – Wadsworth Boulevard to I-25 and US 285 interchange

These corridors were then subdivided into several sub corridors. I-25 from 120th to C-470 for example has been divided into eight sub corridors. In general, the major corridors were subdivided at major interchanges where the number of mainline through lanes changes. **Table 3** shows each of the sub corridors analyzed in more detail in this study as well as the location of identified bottlenecks.

Table 3. Candidate Corridors

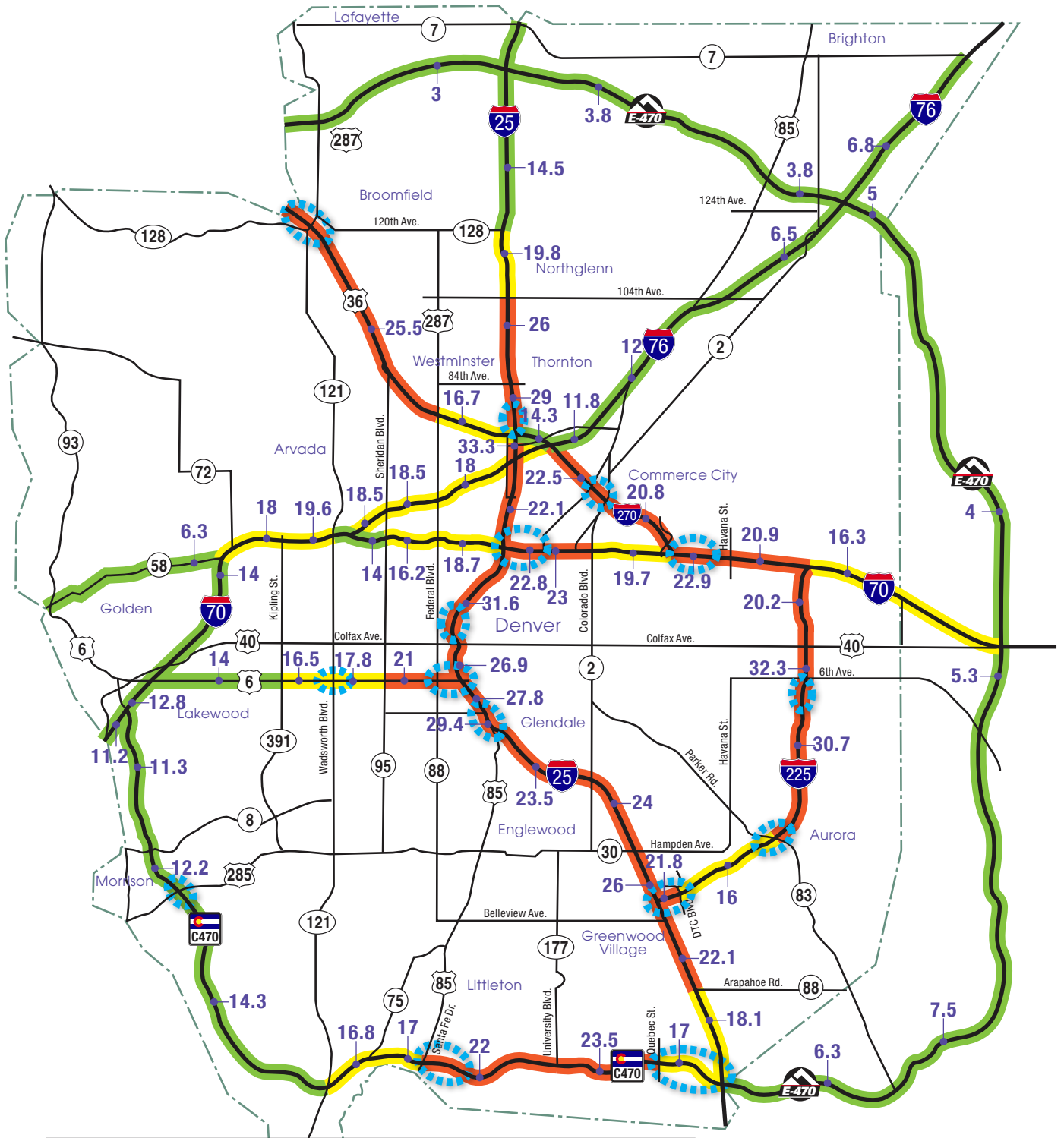
Corridor	Location	Identified Bottleneck(s)?	Bottleneck Directionality?
US 6	Kipling to Sheridan	Yes - Wadsworth	Both - EB and WB
US 6	Sheridan to I-25	Yes - Federal	Both - EB and WB
I-25	C-470 to I-225	No	N/A
I-25	I-225 to Broadway	No	N/A
I-25	Broadway to US 6	Yes - Santa Fe / Alameda	Both - NB and SB
I-25	US 6 to Colfax	No	N/A
I-25	Colfax to 20th Street	Yes - Between Speer & 20th	Both - NB and SB
I-25	20th Street to I-70	No	N/A
I-25	I-70 to US 36	No	N/A
I-25	US 36 to 120th	Yes - Between 84th & US 36	Both - NB and SB
US 36	North of Wadsworth to Sheridan	Yes - Between Interlocken & Wadsworth	Both - EB and WB
US 36	Sheridan to I-25	No	N/A
I-70	Hwy 58 to I-25	No	N/A
I-70	I-25 to I-270	Yes - Between I-25 and York Street	EB only
I-70	I-270 to Pena Boulevard	Yes - East of I-270 interchange	EB only
I-225	I-25 to Parker	Yes - Yosemite to I-25	WB (SB)
I-225	Parker to 6th Ave	Yes - 6th to Alameda and Yale to Parker	SB Only and NB Only
I-225	6th Ave to I-70	No	N/A
I-270	I-76 to I-70	Yes - Vasquez Blvd	Both - EB and WB
C-470	US 285 interchange	Yes	Both - NB (WB) and SB (EB)
C-470	Wadsworth to I-25	Yes - East of Santa Fe and Yosemite to I-25	EB only and Both EB and WB



LEGEND

- XXX** = Average Daily Traffic (in thousands)
(source: 2009 CDOT Volume Map)
- X** = Number of Mainline Through Lanes
- = Region 6 Boundary

Figure 1
Freeway Daily Traffic and Through Lanes



LEGEND





- XXX** = Daily Traffic Volume per Lane (in thousands)
-  = Freeway Bottleneck Location Identified in DRCOG Study
-  = Over 20,000 Vehicles per Lane Daily
-  = 16,000 to 19,999 Vehicles per Lane Daily
-  = Under 15,999 Vehicles per Lane Daily

Figure 2
 Freeway Bottleneck Locations
 and Congestion Index

With the candidate corridors identified, more in depth geometric information was collected for each of the corridors. This information was compiled from data provided by CDOT and also through the review of aerial photography. The geometric data accumulated for each of the candidate corridors included:

- Length of the corridor
- Through lane widths
- Inside and outside shoulder widths
- Depth of pavement on shoulders
- Right-of-Way width
- Interchanges along the corridor with their configurations

Tables showing the recorded geometric information for each of the corridors can be found in **Appendix B** of this report.

V. ATM TREATMENT SCREENING AND SELECTION CRITERIA

With the candidate corridors defined, a series of selection criteria were developed to determine the feasibility of the various ATM treatments. Selection criteria were developed for hard shoulder running, speed harmonization, queue warning, dynamic re-routing and junction control. These criteria are presented in question form; in the evaluation of a given corridor, if the answer to every question is yes then the given treatment is feasible for that corridor. If the answer to one or more of the questions is no, either the measure is not feasible for that corridor or some steps need to be taken to improve the corridor for the implementation of a specific treatment.

Treatments such as traveler information, ramp metering and incident response are currently in use by CDOT throughout the Region 6 system and should continue to be expanded to encompass all freeways within the Denver metropolitan area. This set of selection criteria have not been developed for these treatments since implementation could occur on any of the metro area freeways for these three treatments.

Finally, treatments such as pricing and managed lanes are the responsibility of the High Performance Transportation Enterprise (HPTE) which is involved in the planning and implementation of user based fees and managed lanes. A list of criteria has not been developed for these two treatments as the implementation should be planned and considered on a case by case basis.

A. Criteria for Hard Shoulder Running (HSR)

- Does the corridor have (or the ability to have) shoulders that are wide enough as well as a shoulder pavement thickness deep enough to support vehicular traffic?
- Does the corridor have (or the ability to have) emergency refuge areas?
- Does the corridor have (or the ability to have) median cross over points for emergency vehicle access? If not, will emergency vehicles still be able to quickly gain access to an incident on the freeway when the hard shoulder is in use?
- Is the corridor able to accommodate regularly spaced lane-use signals in order to designate when the shoulder can be used for vehicular traffic?
- Is the nature of the congestion in the corridor such that HSR is a feasible way to address bottlenecks?
- Are the physical characteristics of the corridor appropriate for HSR, including the following:
 - Are existing interchanges adequately spaced?
 - Are there auxiliary lanes between interchanges and if so will they interfere with HSR?
 - Can the hard shoulder travel lane be incorporated within the existing interchange configuration?
 - Is there sufficient right-of-way / topography to expand diverge and merge areas of ramps if necessary?
 - Are there “pinch” points such as bridges that would be cost prohibitive to widen?
- Are there logical beginning and ending points so that a new bottleneck is not introduced?
- Is it possible to carry the hard shoulder through the nearest downstream bottleneck?
 - Are there chokepoints that could be eliminated to make HSR feasible?

B. Criteria for Speed Harmonization

- Does the corridor have (or the ability to have) signs (either overhead or ground-mounted) spaced at regular intervals? (In general, at least one speed / lane control display should be visible to the motorist at all times for maximum effectiveness.)
- What speed enforcement strategies could be implemented along the corridor for maximum effectiveness of variable speed limits?
- Is there unstable flow and / or a high number of crashes related to unstable flow?

C. Criteria for Queue Warning

- Is queue warning feasible in conjunction with speed harmonization?
- Is the nature of congestion such that queue warning could be effective? (The effectiveness is questionable in areas where congestion occurs consistently as drivers come to expect queues so off-peak times should be considered for implementation.)
- Does the corridor have (or the ability to have) signs every 1/3 to 2/3 of a mile?
- Does the corridor have a high number of queue-related collisions (i.e. rear-ends)?
- Are there unexpected queues due to varying queue times, queue lengths, roadway geometry, etc. in the corridor? If so, these unexpected queues could be used to determine when queue warning should be implemented.

D. Criteria for Dynamic Re-routing (Feasibility not studied for this report)

- Are there alternative corridors parallel to the congested freeway segment that can have traffic shifted to them? Of note, dynamic re-routing may be beneficial, however, this treatment requires a significant amount of inter-agency coordination in order to implement and is best approached as part of incident management plan development. Nonetheless, opportunities for re-routing do exist in the Denver area with freeways such as E-470, C-470, I-225 and US 6 providing alternative routes to I-25 and/or I-70.

E. Criteria for Junction Control (Not recommended for Denver Metro Area)

- Are the volumes at the junction heavy for one movement (i.e., mainline) and light for the other movement (i.e., ramp)?
 - Junction control can only work at an on-ramp when mainline has spare capacity
 - Junction control can only work at an off-ramp if the exit ramp has available width to accommodate the additional exit lane
- In general, there are not any freeway locations within the Denver Metro area that meet the above volume or laneage requirements. Therefore, this treatment is not recommended for any of the corridors analyzed in this study.

F. General Criteria for all Active Traffic Management Methods

- Does the corridor have (or the ability to have) reliable communications along the corridor and readily available power sources for equipment?
- Are there adequate staffing resources?

VI. POTENTIAL ATM TREATMENTS FOR CANDIDATE CORRIDORS

With the candidate corridors and the treatment selection criteria defined, the feasibility of each of the ATM treatments for each candidate corridor was determined. The criteria questions were applied to each corridor shown in **Table 4**. Locations along each corridor where one or more of the criteria were not met were noted. Locations where the criteria were not met but could be modified in order to allow for one or all of the ATM techniques to be implemented were also noted. **Appendix B** contains the detailed analysis tables for each of the candidate corridors. In addition to the geometrics for each corridor, these tables also identify recent or future construction projects, the potential opportunities for ATM and which treatments are applicable to the corridor.

The candidate corridors were then divided into three groups based on how effective the treatments are expected to be for the given corridor. **Table 4**, shows a summary of the ATM treatments determined to be feasible and which tier the given corridor is within. In general, corridors shown in Tier 3 are currently under construction or are expected to undergo construction to provide additional capacity for the given freeway corridor. Due to these underway or planned construction projects, ATM treatments are not expected to be needed immediately. However, these corridors should be evaluated again in the future, and the new construction along these corridors should not preclude the implementation of ATM treatments if deemed feasible in the future.

Table 4. Active Traffic Management Treatment Summary

Corridor	Location	Identified Bottleneck(s)?	Bottleneck Directionality?	Active Traffic Management Treatment		
				Hard Shoulder Running	Speed Harmonization	Queue Warning
Tier 1 Corridors - High Potential for Immediate Benefits from ATM Treatments						
I-25	US 36 to 120th	Yes - Between 84th & US 36	Both - NB and SB	X	X	X
I-225	I-25 to Parker	Yes - Yosemite to I-25	WB (SB)		X	X
C-470	Wadsworth to I-25	Yes - East of Santa Fe and Yosemite to I-25	EB only and Both EB and WB	X	X	X
Tier 2 Corridors – Moderate Potential for Immediate Benefits from ATM Treatments						
US 6	Kipling to Sheridan	Yes - Wadsworth	Both - EB and WB		X	X
US 6	Sheridan to I-25	Yes - Federal	Both - EB and WB		X	X
I-25	Lincoln to I-225	No	N/A		X	X
I-25	I-225 to Broadway	No	N/A	X	X	X
I-25	I-70 to US 36	No	N/A		X	X
I-70	Hwy 58 to I-25	No	N/A		X	X
I-70	I-25 to I-270	Yes - Between I-25 and York Street	EB only		X	X
I-70	I-270 to Pena Boulevard	Yes - East of I-270 interchange	EB only		X	X
I-270	I-76 to I-70	Yes - Vasquez Blvd	Both - EB and WB		X	X
Tier 3 Corridors – Due to Construction, Benefits of ATM Treatments are Questionable but Should be Reevaluated in Future						
I-25	Broadway to US 6	Yes - Santa Fe / Alameda	Both - NB and SB		X	X
I-25	US 6 to Colfax	No	N/A		X	X
I-25	Colfax to 20th Street	Yes - Between Speer & 20th	Both - NB and SB		X	X
I-25	20th Street to I-70	No	N/A		X	X
US 36	North of Wadsworth to Sheridan	Yes - Between Interlocken & Wadsworth	Both - EB and WB		X	X
US 36	Sheridan to I-25	No	N/A		X	X
I-225	Parker to 6th Ave	Yes - 6th to Alameda and Yale to Parker	SB Only and NB Only		X	X
I-225	6th Ave to I-70	No	N/A		X	X
C-470	US 285 interchange	Yes	Both - NB (WB) and SB (EB)		X	X

VII. IMPLEMENTATION AND LAYOUT OF ATM TREATMENTS

A. *Implementation Considerations*

During the planning and design of all future freeway improvement projects within the Denver metro area, more detailed consideration should be given to planning and implementing ATM treatments found to be potentially beneficial. Consideration should be given to implementing, in the short term, one or more of the ATM treatments identified in this report for corridors in Tier 1. If the opportunity arises for the planning, design or implementation of the treatments identified for corridors in Tier 2 and 3, every effort should be made not to preclude the implementation of ATM on these corridors.

There are also several considerations with regard to implementation for some of the individual ATM treatments. The following provides a high-level description of the ATM operations for a corridor with hard shoulder running, speed harmonization, and queue warning treatments.

Hard Shoulder Running

This treatment will utilize the full width shoulder as an additional traveled lane to add capacity during peak periods. Static signs with lane-use signals and overhead VMS will be in place over the shoulder lane roughly every half mile to indicate the status (open or closed) of the lane. The concept is that the status of the shoulder would be known to all users entering or remaining on the facility. CCTV will provide surveillance to visually confirm whether the lane is clear of obstructions or incidents. Signing and striping along the corridor would be modified to accommodate the peak use of the shoulder as a travelled lane. Emergency pull-outs will be provided to allow for a safe refuge for disabled vehicles.

Hard shoulder running can be carried through interchanges, however, care should be taken regarding how the hard shoulder interacts with merge and diverge points at ramps. The appropriate signing and striping should be in place along the freeway in order to clearly delineate the travel lanes and minimize driver confusion.

Conceptual layouts of the C-470 corridor can be found in the next section of this report.

Speed Harmonization

As previously mentioned, the CDOT Division of Transportation Development (DTD) is currently completing research to develop an algorithm for determining how to vary speeds for speed harmonization. This algorithm is based on the interaction between freeway density and speed. This research has focused on four lane freeway segments such as segments along C-470 but ultimately will also include all freeway cross sections within the Denver metro area. This algorithm will reduce the uncertainty about which corridors are good candidates for speed harmonization.

This treatment includes displaying variable speed limits on ground mounted and overhead VMS based upon prevailing traffic conditions. The speed limits would be adjusted and posted for different segments within the corridor, as appropriate. The speed harmonization system would use MVRD and TTI devices to measure and collect the volume, occupancy, speed and travel

time data along the corridor. This data will be sent back to the CTMC for processing and comparison against an ATM algorithm. The ATM algorithm would alter the VMS to post a speed limit according to certain conditions being satisfied. These posted variable speed limits would then smooth, or harmonize, the traffic flow in an attempt to match the travel characteristics with an appropriate safe speed limit and increase capacity. The VMS signs would replace the existing static regulatory speed limit signs. CCTV cameras may be used to monitor the conditions, depending upon the level of automation in the system. Finally, enforcement of the variable speed limit will also need to be carefully considered.

Queue Warning and Incident Response

An automated queue detection system will likely increase the staffing requirements needed for the implementation of the queue warning treatment. In addition, visual confirmation by an operator is necessary to coordinate with public safety and courtesy patrol if there is an incident on the freeway that is the cause of the queue, especially during an off-peak time period.

The queue warning system would utilize much of the same data as the speed harmonization system, and would be used in conjunction with that ATM treatment. However, the queue warning system would use the detector data to identify abrupt changes in travel conditions to detect stop-and-go traffic. In turn, an advisory message would be posted to the VMS notifying roadway users that they are approaching the back of a queue with the intention of preventing related crashes and secondary incidents.

All ATM Treatments

Coordination with the Colorado Transportation Management Center (CTMC) and local agencies is very important for ATM treatments to be successful. Prior to the implementation of ATM treatments, clear roles should be identified among CDOT staff with Region 6 and the CTMC as to who is responsible for the maintenance and day to day operation of the ATM treatments in the field. Finally, each ATM treatment should be consistently implemented throughout the Region.

B. Feasibility and Conceptual Layouts of ATM Treatments for Specific Corridors

This section discusses the feasibility of the identified ATM treatments for specific corridors and also provides conceptual layouts for the C-470 corridor. For this more in depth analysis, the top rated corridors from the Active Traffic Management Treatment Summary Table were evaluated. **Table 5** summarizes these select corridors. Following the table there is a detailed discussion for each of the corridors describing the reasoning, including any limitations, for the recommendations.

Table 5. Corridors for Detailed Analysis

Freeway	Segment	Direction	Hard Shoulder Running Potential	Queue Warning and Speed Harmonization Potential
C-470	Wadsworth Boulevard to I-25	EB	Yes Outside shoulder	Yes
		WB	Yes Outside shoulder	Yes
I-25	US36/I-270 to 120 th Avenue	NB	Yes Inside or outside shoulders. To be evaluated further in the North I-25 PEL Study	Yes
		SB		Yes
I-225	I-25 to Parker Road	NB	No	Yes
		SB	Yes Inside shoulder if weave between DTC Blvd and I-25 is addressed	Yes
I-270	I-76 to I-70	EB	No	Yes
		WB	No	Yes

C-470

The section of C-470 from Wadsworth Boulevard to I-25 is a potential candidate for queue warning, and speed harmonization; the segment from Santa Fe Boulevard to I-25 is a feasible candidate for hard shoulder running. This Wadsworth Boulevard to I-25 segment is approximately 12 miles long with four through lanes, two in each direction. The inside shoulder width varies from four to six feet eastbound and four to seven feet westbound. The outside shoulder varies from seven to 21 feet eastbound and six to 14 feet westbound. None of the on-ramps add lanes, except for the on-ramp from I-25 to westbound C-470; this lane drops at the Quebec Street exit. The on-ramp from Quebec Street to eastbound C-470 also adds a lane; this lane drops at I-25.

Hard Shoulder Running could be considered for the outside shoulder. For westbound traffic, the hard shoulder running could begin as an extension from the off-ramp lane drop at Quebec Street and extend to Santa Fe Boulevard. Eastbound hard shoulder running could begin from the on-ramp at Santa Fe Boulevard and have a logical end point at the off-ramp to I-25. The existing bridges could be choke points for having adequate width for hard shoulder running and may need to be modified in order to allow for hard shoulder running. There are three bridges for the westbound direction and five bridges for the eastbound direction.

This section of C-470 would also be good for queue warning and speed harmonization in both westbound and eastbound directions.

Figure 3 and **Figure 4** show conceptual layouts of what hard shoulder running, queue warning and speed harmonization might look like along the C-470 corridor. Of note, these two figures only show a concept for the eastbound direction but similar equipment would be needed for implementation in the westbound direction. Option 1 (**Figure 3**) shows a concept that includes full overhead signs while Option 2 (**Figure 4**) shows a slightly more cost effective concept that utilizes more ground mount and cantilever signs. In addition, **Figure 5** shows an elevation view of what the proposed signs look like.

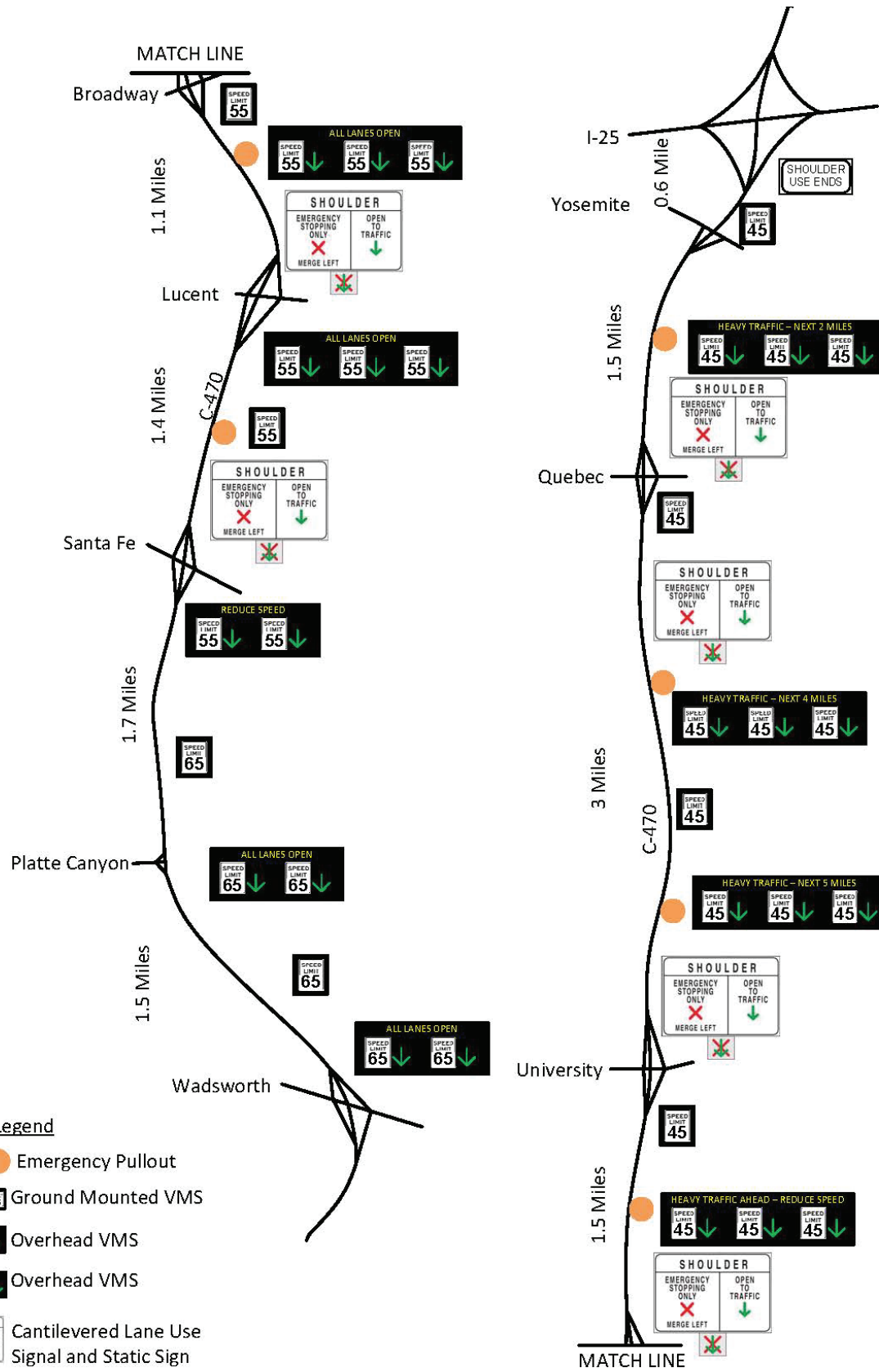


Figure 3
C-470 Conceptual ATM Layout -
Option 1

NORTH

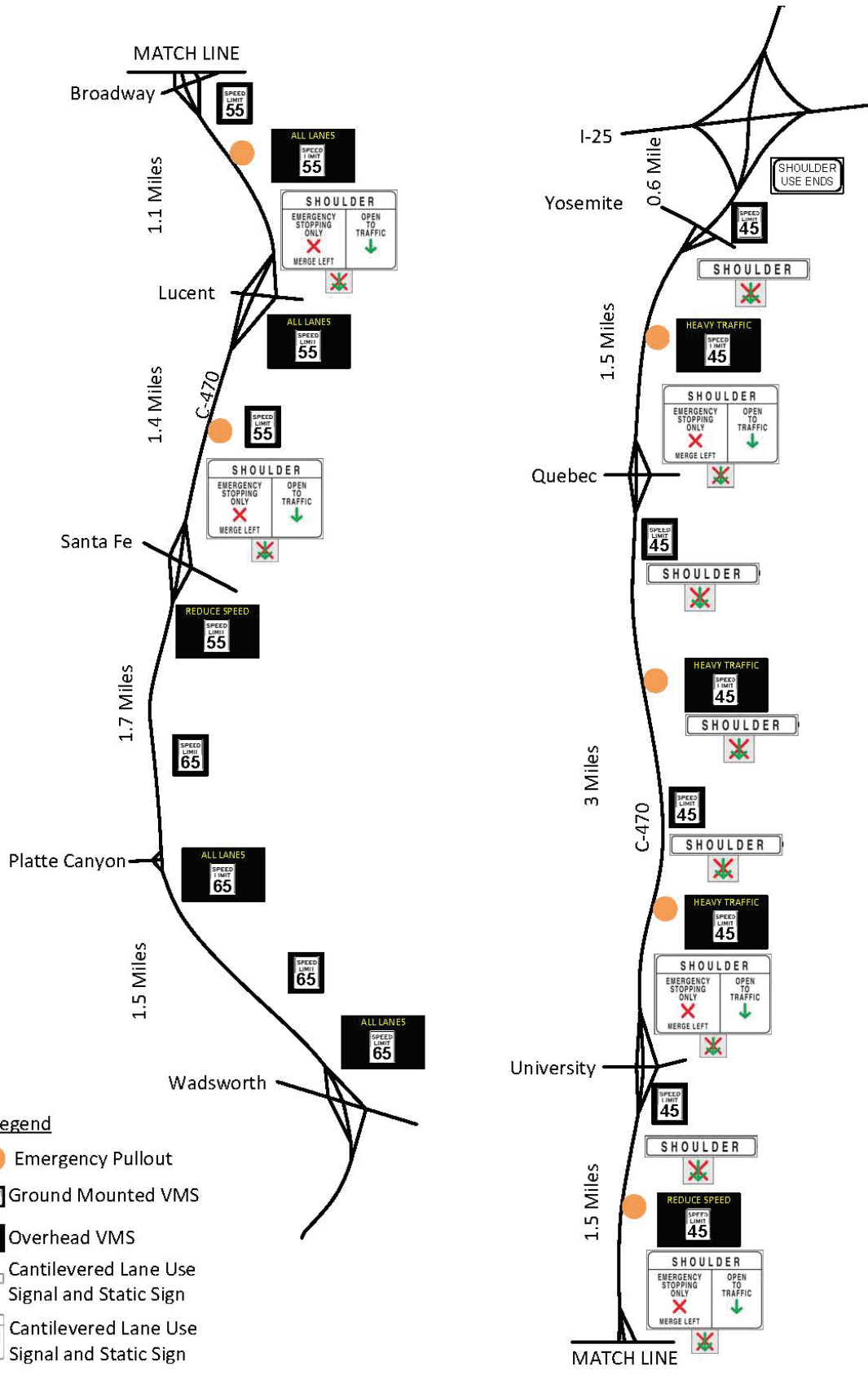
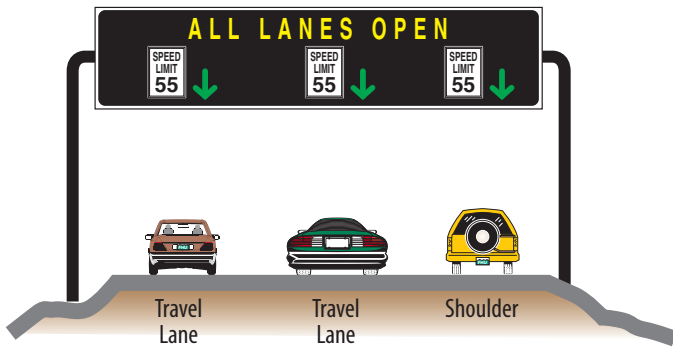
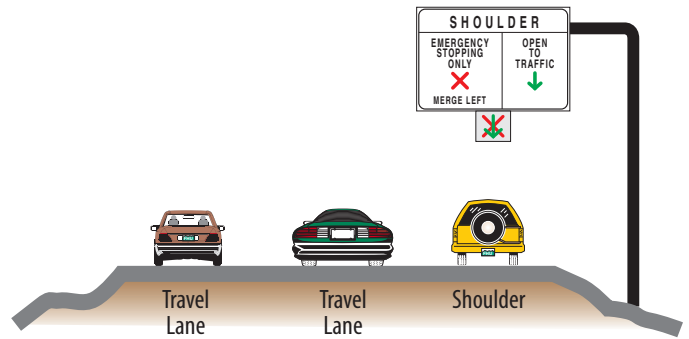


Figure 4
C-470 Conceptual ATM Layout - Option 2

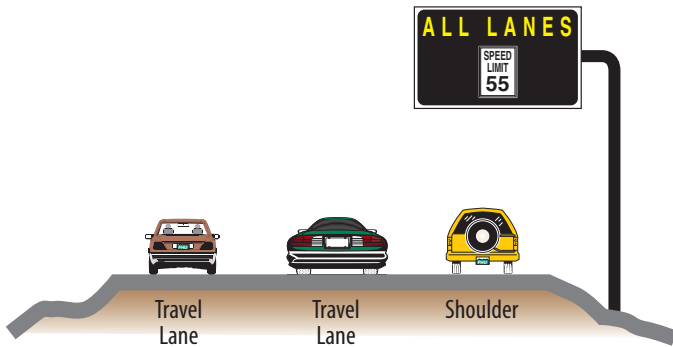


Speed Harmonization and Queue Warning Sign Bridge

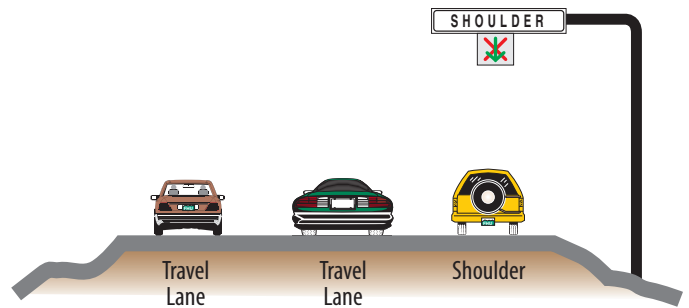


Hard Shoulder Running Cantilever Sign 1
(Also Included in Option 2)

**C-470 Conceptual Layout
OPTION 1**



Speed Harmonization and Queue Warning Cantilever



Hard Shoulder Running Cantilever Sign 2

**C-470 Conceptual Layout
OPTION 2**

Figure 5
CONCEPTUAL SIGN LAYOUTS

I-25 – US 36 / I-270 to 120th Avenue

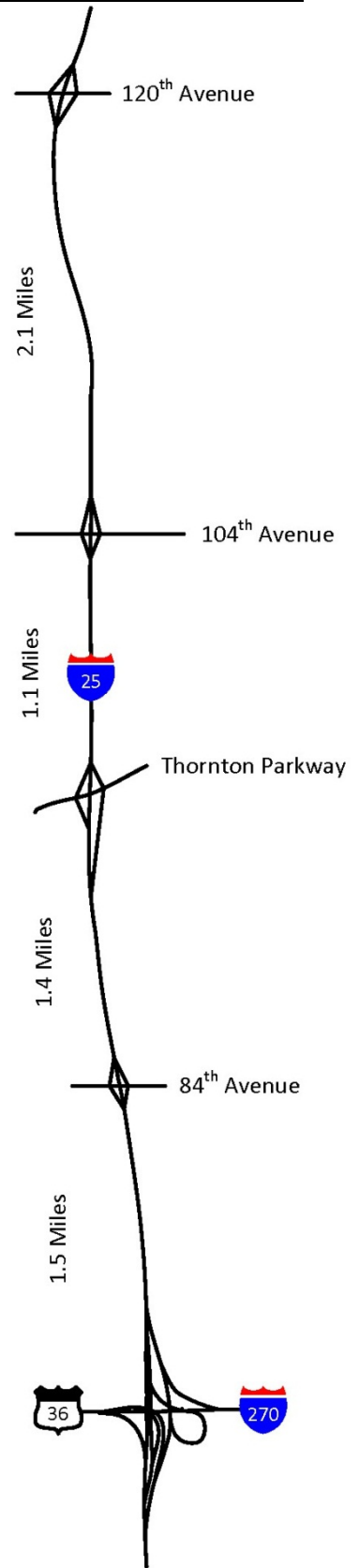
The section of southbound I-25 from 120th Avenue to US36/I-270 is a potential candidate for hard shoulder running, queue warning, and speed harmonization. This section is approximately six miles long with three to five lanes. The inside shoulder width varies from 10 to 21 feet and the outside shoulder width varies from 5 to 12 feet. Beginning at 120th Avenue, two on-ramp lanes drop and three through lanes continue. Both 104th Avenue and Thornton Parkway on-ramps have one lane merging onto the mainline, and the 84th Avenue on-ramp adds one lane to the mainline for a total of four through lanes. Between 84th Avenue and I-270, an additional left lane develops. This left lane becomes a dedicated exit lane to the I-270 flyover and there is also a through / exit lane from I-25, thus providing a two-lane exit to I-270. Immediately south of the I-270 exit, there are four through lanes, an additional left lane soon develops and becomes the access to the HOV facility into downtown Denver.

Hard shoulder running could be considered on either the inside or outside shoulder along this portion of southbound I-25. Inside hard shoulder running could begin at the bus lane in the median of the I-25 ramp access to the 120th Avenue park-n-Ride. This would require some reconfiguration of the bus lane which currently exclusively serves northbound I-25; this would include some barrier modification and addition of gates. The inside hard shoulder running would have a logical ending point at the left lane addition just north of the I-270 exit, provided there is sufficient traffic to make this a logical terminus. Outside hard shoulder running could begin at 120th Avenue; one of the two on-ramp lanes could feed into the hard shoulder. The ending point for outside hard shoulder running would likely be into the lane that is added at the 84th Avenue on-ramp. This right lane eventually becomes an exit-only lane for I-76 westbound. Again, volumes would have to be reviewed in order to assess whether this would be a logical stopping point or whether it would create another bottleneck.

Speed harmonization and queue warning could be implemented along the entire segment. Since the interchanges are at least a mile apart, there is adequate room to sign and have variable speed limits for speed harmonization.

I-25 Northbound between US 36 and 120th Avenue has a bottleneck between US 36 and 84th Avenue. This segment needs to be further studied to determine if Active Traffic Management treatments after the bottle neck, instead of before, would yield any safety or operational benefits.

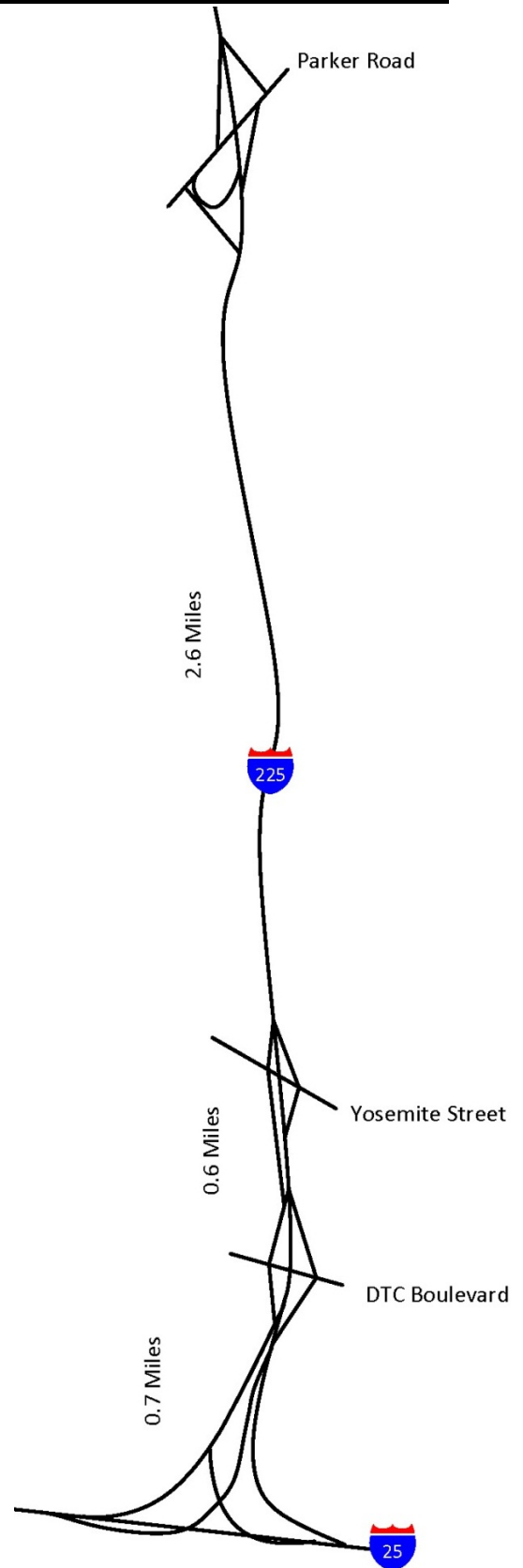
The further study of these segments would be most appropriate in the upcoming I-25 North Planning and Environmental Linkages study.



I-225 – I-25 to Parker Road

The section of I-225 from I-25 to Parker Road is a potential candidate for hard shoulder running, queue warning, and Speed harmonization. This section is approximately four miles long with three to five lanes southbound and three to four lanes northbound. In the southbound direction, beginning at Parker Road, the three through lanes becomes four through lanes after the additional lanes from the Parker Road on-ramps merge into southbound I-225. At Yosemite there is a two lane exit, at which one of the four mainline through lanes drops. There is also a lane drop at the DTC Boulevard exit so there are only two mainline through lanes over DTC Boulevard; however the on-ramp from DTC Boulevard adds a lane to return to three through lanes. These lane drops are a significant cause of the recurring bottleneck along this stretch of I-225. The I-25 exit splits the lanes with the left lane heading towards southbound I-25, the right lane heading towards northbound I-25 and the middle lane being able to make either movement.

Inside hard shoulder running along southbound I-225 seems more feasible than outside hard shoulder running. The inside shoulder width southbound ranges from six to twenty feet. Southbound hard shoulder running would only be beneficial if the existing weave from DTC Boulevard to Southbound I-225 was first corrected. The existing weave is a Type B weave; the traffic from DTC Boulevard must make one lane change to access southbound I-225. This merge must occur in approximately one-quarter of a mile. If the existing weave was improved or removed then hard shoulder running could begin between Parker Road and Yosemite before the lane drop at the Yosemite off-ramp. However, the removal of this weaving section will likely be very difficult. In addition, existing traffic volumes during non-peak hours at the I-25 exit would need to be investigated to ensure that non-peak volume levels would allow for acceptable levels of service with hard shoulder running in place. Finally, widening of the inside shoulder throughout this segment is constrained by the light rail in the center median.



Northbound I-225 begins at I-25 with two lanes coming from northbound I-25 and one lane coming from southbound I-25 for a total of three through lanes. The on-ramp from DTC Boulevard adds an additional through lane for a total of four lanes. The on-ramp from Yosemite merges into the existing through lanes. At Parker Road, the right lane becomes an exit only lane with a two-lane exit to Parker Road. Three through lanes continue north past Parker Road. This location on northbound I-225 is currently identified as a bottleneck. However, widening projects along I-225 are currently under design in order to remove the bottleneck at Parker Road. Therefore, hard shoulder running does not appear to be beneficial for northbound traffic at this time due to existing geometric conditions and the planned widening projects along I-225.

This section of I-225 would be good for queue warning and speed harmonization in both northbound and southbound directions.

I-270

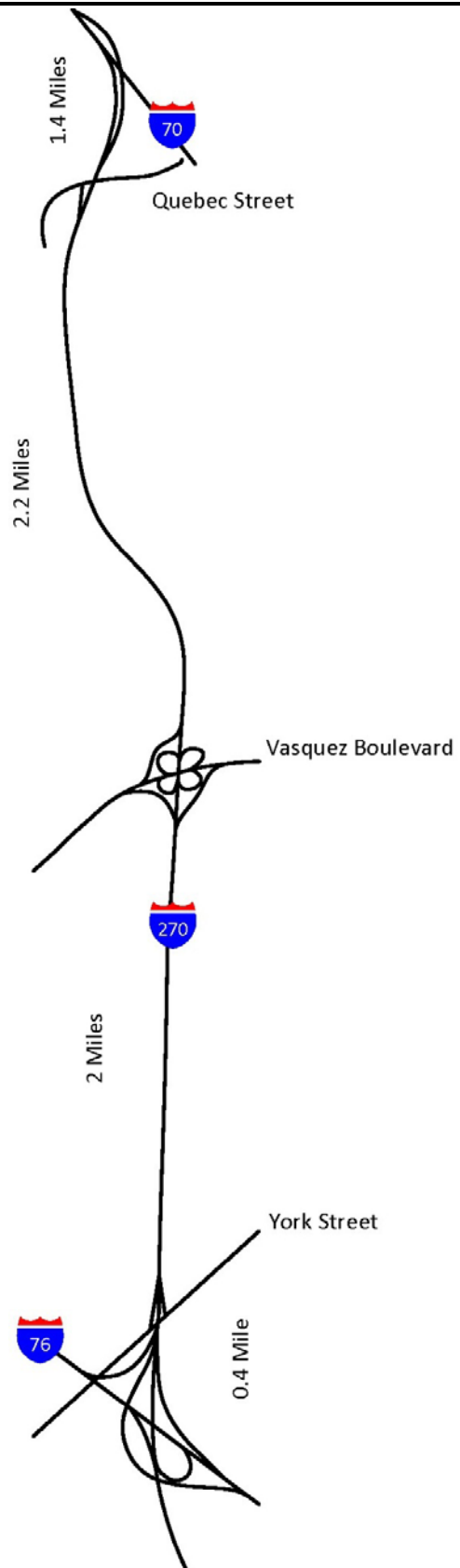
The section of I-270 from I-76 to I-70 is a potential candidate for queue warning, and speed harmonization, and was also considered for hard shoulder running. This section is approximately six miles long with four through lanes, two in each direction. The inside shoulder width varies from four to thirty feet eastbound and six to 30 feet westbound. The outside shoulder width varies from eight to 15 feet both eastbound and westbound. None of the on-ramps add through lanes.

Hard shoulder running could be considered for the inside shoulder for westbound I-270. However, there are currently many bridges with substandard shoulder widths that would have to be widened to accommodate a full width shoulder. These locations include 60th Avenue, Brighton Boulevard, Sand Creek, and the Platte River. If these roadway widening improvements were made, then inside hard shoulder running could begin shortly after the departure from I-70 westbound. The Hard Shoulder would then end with a merge back into the existing through lanes after the exit for I-76. However, these improvements are significant, and it is more practical that a third freeway lane be added to widen the highway in lieu of a full roadway reconstruction project where multiple bridges are widened just to accommodate driving on the shoulder during peak periods.

Outside hard shoulder running is not recommended due to the cloverleaf ramp configuration at Vasquez Boulevard.

Eastbound hard shoulder running does not have a logical ending location and is not recommended at this time.

This section of I-270 would be good for queue warning and speed harmonization in both westbound and eastbound directions.



C. Crash Data for Top Candidate Corridors

In addition to geometrics, three-years worth of crash data (7/1/2006 – 6/30/2009) for each of the top tiered candidate corridors discussed in the previous section was evaluated to determine if patterns exist that could be addressed with ATM treatments. The assessment of the magnitude of safety problems on select highway sections has been refined through the use of Safety Performance Function (SPF) methodology. The SPF reflects the complex relationship between exposure (measured in ADT) and the accident count for a section of roadway measured in accidents per mile per year (APMPY). The SPF models provide an estimate for the expected accident frequency for each interchange influence area, for a range of ADT, among similar facilities. SPF functions are limited to mainline accidents only and as such do not include accidents that occur on ramps.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF will represent a normal or expected number of accidents at a specific level of ADT, then the degree of deviation from the norm can be stratified to represent specific levels of safety.

- LOSS-I – Indicates low potential for accident reduction
- LOSS-II – Indicates better than expected safety performance
- LOSS-III – Indicates less than expected safety performance
- LOSS-IV – Indicates high potential for accident reduction

Table 6 shows a summary of the top crash types for each corridor and also the overall level of service of safety (LOSS) for each corridor.

Table 6. Summary of Existing Crash Data

Freeway	Segment	Freeway Mainline Crashes				LOSS Category
		Total	Most Frequent	2nd Most Frequent	3rd Most Frequent	
I-25	US 36 to 120th Avenue	1,123	Rear end (673)	Sideswipe same direction (198)	Concrete Barrier (119)	II
I-225	I-25 to Parker Road	380	Rear end (211)	Sideswipe same direction (69)	Concrete Barrier (68)	II
C-470	Wadsworth Blvd to I-25	860	Rear end (404)	Sideswipe same direction (113)	Cable Rail (82)	II
I-270	I-76 to I-70	404	Rear end (214)	Sideswipe same direction (89)	Guard Rail (29)	II

As can be seen in this table, the most frequent crash types among these corridors are nearly identical with rear end and sideswipe same direction crashes being the most common followed by freeway barrier type crashes. Given that rear end and sideswipe crashes are generally related to congestion, it is likely that implementation of ATM treatments on these corridors could help to reduce the number of these type of crashes similar to European applications.

D. ATM Treatment Cost Estimates

This section provides a brief summary of the assumptions made to complete cost estimates for the various ATM treatments and also the conceptual layouts for C-470.

Speed Harmonization and Queue Warning Cost Per Mile

The cost estimate in **Table 7** is a conceptual cost estimate for deploying speed harmonization and queue warning on a per mile basis on a typical roadway. This estimate includes costs for installing ITS instrumentation and infrastructure to allow for data collection, support roadway monitoring and operations, and display real-time information regarding speed limits and congestion warning to roadway users. The major ITS devices include CCTV, MVRD, TTI, and overhead and ground-mount VMS. As shown, there are two options. The difference is that Option 1 includes a wider VMS as a means to provide real-time traveler information for individual lanes. Conversely, the Option 2 concept includes a smaller VMS that is cantilevered and primarily used for posting of the variable speed limit. The estimate assumes that devices would be placed together on poles whenever possible and that fiber and power are generally available and in the vicinity of proposed devices. Furthermore, the estimate does not include any cost for civil reconstruction of the roadway. A more detailed estimate should be conducted with the final cost estimate reflecting the actual field conditions with existing equipment and desired layout of the ATM design.

Table 7. Speed Harmonization and Queue Warning Cost Per Mile

Item	Unit	Unit Cost	Option 1		Option 2	
			Quantity	Estimated Cost	Quantity	Estimated Cost
Overhead VMS (Sign bridge over all lanes)	Each	\$400,000	1	\$ 400,000	0	\$ -
Overhead VMS (Cantilever over one lane)	Each	\$230,000	0	\$ -	1	\$230,000
Ground Mount VMS	Each	\$100,000	1	\$100,000	1	\$100,000
CCTV	Each	\$15,000	1	\$15,000	1	\$15,000
MVRD	Each	\$10,000	2	\$20,000	2	\$20,000
TTI	Each	\$10,000	0.5	\$5,000	0.5	\$5,000
Power Feed and Transformer Locations	Each	\$50,000	2	\$100,000	2	\$100,000
Fiber	Mile	\$30,000	1	\$ 30,000	1	\$30,000
ITS Subtotal				\$670,000		\$500,000
Miscellaneous Signing	Mile	\$5,000	1	\$5,000	1	\$5,000
Miscellaneous Grading	Mile	\$5,000	1	\$5,000	1	\$5,000
Civil Subtotal				\$10,000		\$10,000
	% Range		% Used	Estimated Cost	% Used	Estimated Cost
Project Construction Bid Items	Project Dependent			\$680,000		\$510,000 (A)
Contingency	15-30% of A		30%	\$204,000	30%	\$153,000 (B)
Construction Signing and Traffic Control	5-25% of A+B		10%	\$88,400	10%	\$ 66,300 (C)
Mobilization	4-7% of A+B+C		7%	\$68,068	7%	\$51,05 (D)
Total Construction Bid Items	(A+B+C+D)			\$1,040,468		\$780,351 (E)
Utilities	1-3% of E		3%	\$31,214	3%	\$23,411 (F)
Misc. Force Account	15% of E		15%	\$156,070	15%	\$117,053 (G)
Total Construction Items, CI	(E+F+G)			\$1,227,752		\$920,815 (H)
Construction Engineering	10-15% of H		12%	\$147,330	12%	\$110,498 (I)
Construction Engineering Indirects	3.4% of H		3.4%	\$41,744	3.4%	\$31,308 (J)
Engineering Design	10% of H		10%	\$122,775	10%	\$92,082 (K)
Software and Integration				\$70,000		\$70,000 (L)
Total Project Cost	(H+I+J+K+L)			\$1,609,601		\$1,224,703 *

* The total cost does not include annualized cost for Maintenance and Operations (M&O). Annualized M&O costs would include additional personal, equipment, spare parts, courtesy patrol, and other related items due to the increased infrastructure and associated responsibilities.

C-470 Eastbound – Wadsworth to I-25

Table 8 contains a planning-level cost estimate for implementing speed harmonization and queue warning in the eastbound direction of travel for C470 from Wadsworth Boulevard to I-25; and hard shoulder running from Santa Fe Boulevard to I-25. There are two options presented in the table. The major difference between the two is that Option 1 includes a wider VMS spanning all lanes of travel, including the shoulder. Option 1 uses these wider VMS as a means to indicate that the shoulder is open to travel and to give individual lane use information. Conversely, the Option 2 concept includes a smaller VMS that is cantilevered over the shoulder and primarily used for posting of the variable speed limit. Option 2 uses supplemental static signs with lane-use signals to notify drivers as to whether the shoulder is open or closed.

Both ATM options seek to provide real-time information roughly every half mile, using a mix of primary and supplemental electronic signs. Both options also include cost to reconstruct the shoulder from Santa Fe Boulevard to I-25, make geometric improvements at the on-ramps to facilitate the new merge condition that would be in place with the shoulder open to traffic, and a full mill and overlay for the shoulders along this stretch of C-470. The cost also provisions for half a dozen emergency pull-outs between interchanges to provide refuge for disable vehicles since there will not be a shoulder available during peak periods.

Table 9 and **Table 10** have also been provided to show what costs might be expected if either speed harmonization / queue warning or hard shoulder running are constructed individually on C-470. Of note, the cost for hard shoulder running between Option 1 and Option 2 is the same because the number of lane use signal signs is the same between the two options.

Table 8. C-470 ATM Conceptual Layout Planning-Level Costs

Item	Unit	Unit Cost	Option 1		Option 2	
			Quantity	Estimated Cost	Quantity	Estimated Cost
Overhead VMS (Sign bridge over all lanes)	Each	\$400,000	9	\$3,600,000	0	\$ -
Overhead VMS (Cantilever over one lane)	Each	\$230,000	0	\$ -	9	\$2,070,000
Ground Mount VMS	Each	\$100,000	8	\$800,000	8	\$800,000
Lane Use Signal (Full Static Sign)	Each	\$85,000	6	\$510,000	5	\$ 425,000
Lane Use Signal (Supplemental Static Sign)	Each	\$75,000	0	\$ -	5	\$ 375,000
CCTV	Each	\$15,000	12	\$180,000	12	\$180,000
MVRD	Each	\$10,000	24	\$240,000	24	\$240,000
TTI	Each	\$10,000	6	\$60,000	6	\$60,000
Power Feed and Transformer Locations	Each	\$50,000	24	\$1,200,000	27	\$1,350,000
Fiber	Mile	\$30,000	12.3	\$369,000	12.3	\$369,000
ITS Subtotal				\$6,959,000		\$5,869,000
Reconstruct Shoulder	Mile	\$360,000	9	\$3,240,000	9	\$3,240,000
On-Ramp Widening	Each	\$90,000	4	\$360,000	4	\$360,000
Mill and Overlay Roadway	Mile	\$195,000	9	\$1,755,000	9	\$1,755,000
Restriping and Miscellaneous Signing	Mile	\$10,000	9	\$90,000	9	\$90,000
Emergency Pullout	Each	\$90,000	6	\$540,000	6	\$540,000
Civil Subtotal				\$5,985,000		\$5,985,000
		% Range	% Used	Estimated Cost	% Used	Estimated Cost
Project Construction Bid Items	Project Dependent			\$12,944,000		\$11,854,000 (A)
Contingency	15-30% of A	30%		\$3,883,200	30%	\$3,556,200 (B)
Construction Signing and Traffic Control	5-25% of A+B	10%		\$1,682,720	10%	\$1,541,020 (C)
Mobilization	4-7% of A+B+C	7%		\$1,295,694	7%	\$1,186,585 (D)
Total Construction Bid Items	(A+B+C+D)			\$19,805,614		\$18,137,805 (E)
Utilities	1-3% of E	3%		\$594,168	3%	\$544,134 (F)
Misc. Force Account	15% of E	15%		\$2,970,842	15%	\$2,720,671 (G)
Total Construction Items, CI	(E+F+G)			\$23,370,624		\$21,402,610 (H)
Construction Engineering	10-15% of H	12%		\$2,804,475	12%	\$2,568,313 (I)
Construction Engineering Indirects	3.4% of H	3.4%		\$794,601	3.4%	\$727,689 (J)
Engineering Design	10% of H	10%		\$2,337,062	10%	\$2,140,261 (K)
Software and Integration				\$750,000		\$750,000 (L)
Total Project Cost	(H+I+J+K+L)			\$30,056,762		\$27,588,873 *

* The total cost does not include annualized cost for Maintenance and Operations (M&O). Annualized M&O costs would include additional personal, equipment, spare parts, courtesy patrol, and other related items due to the increased infrastructure and associated responsibilities.

Table 9. Speed Harmonization / Queue Warning Planning-Level Costs

Item	Unit	Unit Cost	Option 1		Option 2	
			Quantity	Estimated Cost	Quantity	Estimated Cost
Overhead VMS (Sign bridge over all lanes)	Each	\$400,000	9	\$3,600,000	0	\$ -
Overhead VMS (Cantilever over one lane)	Each	\$230,000	0	\$ -	9	\$2,070,000
Ground Mount VMS	Each	\$100,000	8	\$800,000	8	\$800,000
CCTV	Each	\$15,000	12	\$180,000	12	\$180,000
MVRD	Each	\$10,000	24	\$240,000	24	\$240,000
TTI	Each	\$10,000	6	\$60,000	6	\$60,000
Power Feed and Transformer Locations	Each	\$50,000	24	\$1,200,000	24	\$1,200,000
Fiber	Mile	\$30,000	12.3	\$369,000	12.3	\$369,000
ITS Subtotal				\$6,449,000		\$4,919,000
Miscellaneous Signing	Mile	\$ 5,000	12.3	\$61,500	12.3	\$61,500
Miscellaneous Grading	Mile	\$5,000	12.3	\$61,500	12.3	\$61,500
Civil Subtotal				\$123,000		\$123,000
	% Range		% Used	Estimated Cost	% Used	Estimated Cost
Project Construction Bid Items	Project Dependent			\$6,572,000		\$5,042,000 (A)
Contingency	15-30% of A		30%	\$1,971,600	30%	\$1,512,600 (B)
Construction Signing and Traffic Control	5-25% of A+B		10%	\$854,360	10%	\$655,460 (C)
Mobilization	4-7% of A+B+C		7%	\$657,857	7%	\$504,704 (D)
Total Construction Bid Items	(A+B+C+D)			\$10,055,817		\$7,714,764 (E)
Utilities	1-3% of E		3%	\$301,675	3%	\$231,443 (F)
Misc. Force Account	15% of E		15%	\$1,508,373	15%	\$1,157,215 (G)
Total Construction Items, CI	(E+F+G)			\$11,865,865		\$9,103,422 (H)
Construction Engineering	10-15% of H		12%	\$1,423,904	12%	\$1,092,411 (I)
Construction Engineering Indirects	3.4% of H		3.4%	\$403,439	3.4%	\$309,516 (J)
Engineering Design	10% of H		10%	\$1,186,587	10%	\$910,342 (K)
Software and Integration				\$750,000		\$750,000 (L)
Total Project Cost	(H+I+J+K+L)			\$15,629,795		\$12,165,691 *

* The total cost does not include annualized cost for Maintenance and Operations (M&O). Annualized M&O costs would include additional personal, equipment, spare parts, courtesy patrol, and other related items due to the increased infrastructure and associated responsibilities.

Table 10. Hard Shoulder Running Planning-Level Costs

Item	Unit	Unit Cost	Quantity	Estimated Cost
Overhead VMS (Sign bridge over all lanes)	Each	\$400,000	0	\$ -
Overhead VMS (Cantilever over one lane)	Each	\$230,000	1	\$230,000
Lane Use Signal (Full Static Sign)	Each	\$85,000	5	\$425,000
Lane Use Signal (Supplemental Static Sign)	Each	\$75,000	5	\$375,000
CCTV	Each	\$15,000	9	\$135,000
Power Feed and Transformer Locations	Each	\$50,000	9	\$450,000
Fiber	Mile	\$30,000	9	\$270,000
ITS Subtotal				\$1,885,000
Reconstruct Shoulder	Mile	\$360,000	9	\$3,240,000
On-Ramp Widening	Each	\$90,000	4	\$360,000
Mill and Overlay Roadway	Mile	\$195,000	9	\$1,755,000
Restriping and Miscellaneous Signing	Mile	\$ 10,000	9	\$90,000
Emergency Pullout	Each	\$90,000	6	\$540,000
Civil Subtotal				\$5,985,000
		% Range	% Used	Estimated Cost
Project Construction Bid Items		Project Dependent		\$7,870,000 (A)
Contingency		15-30% of A	30%	\$2,361,000 (B)
Construction Signing and Traffic Control		5-25% of A+B	10%	\$1,023,100 (C)
Mobilization		4-7% of A+B+C	7%	\$787,787 (D)
Total Construction Bid Items		(A+B+C+D)		\$12,041,887 (E)
Utilities		1-3% of E	3%	\$361,257 (F)
Misc. Force Account		15% of E	15%	\$1,806,283 (G)
Total Construction Items, CI		(E+F+G)		\$14,209,427 (H)
Construction Engineering		10-15% of H	12%	\$1,705,131 (I)
Construction Engineering Indirects		3.4% of H	3.4%	\$483,121 (J)
Engineering Design		10% of H	10%	\$1,420,943 (K)
Software and Integration				\$750,000 (L)
Total Project Cost		(H+I+J+K+L)		\$18,568,622 *

* The total cost does not include annualized cost for Maintenance and Operations (M&O). Annualized M&O costs would include additional personal, equipment, spare parts, courtesy patrol, and other related items due to the increased infrastructure and associated responsibilities.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this report, there are several ATM treatments that CDOT Region 6 should continue to utilize and several others that should be considered for use within the Denver Metro area. Existing treatments that are very effective and could be expanded system-wide, where appropriate, include:

- Traveler Information
- Ramp Metering
- Incident Response (Courtesy Patrol)
- Pricing
- And, Managed Lanes

Treatments not currently in use that were found to be feasible for the Denver area include:

- Hard Shoulder Running
- Speed Harmonization
- And, Queue Warning

In addition, treatments such as Dynamic Signing and Re-routing could also be implemented within the Denver area but require more inter-agency coordination and are best approached as part of an incident management plan. As such, these treatments were not evaluated in depth in this feasibility study. However, it is worth noting that opportunities for re-routing do exist in the Denver area with freeways such as E-470, C-470, I-225 and US 6 providing alternative routes to I-25 and/or I-70.

A. ATM Criteria and Conceptual Layouts

The entire Denver area freeway system was reviewed to determine which corridors / segments are likely to be congested or have bottlenecks. Criteria, in the form of a series of questions, were developed to aid in identifying which ATM treatments might be applicable to a given corridor. These criteria included geometrics, traffic volumes, known bottleneck locations and crash data. **Table 4** of this report shows which of the three ATM treatments not currently in use in Denver have been determined to be feasible for each of the candidate corridors. Through the use of the ATM treatment evaluation criteria, three corridors in **Table 4** were identified as top priority candidates for the implementation of ATM treatments. These corridors include:

- I-25 from US 36 to 120th Avenue
- I-225 from I-25 to Parker Road
- And, C-470 from Wadsworth Boulevard to I-25

To illustrate concepts, two layout options of hard shoulder running, speed harmonization and queue warning have been developed for the C-470 corridor and can be seen on **Figure 3** and

Figure 4. Figure 5 shows elevation views of each of the possible ATM signs. Finally, planning-level cost estimates have also been developed for the options on C-470 to provide a general idea of what implementation of all three ATM treatments might cost. Cost estimates on a per mile basis were also developed for speed harmonization and queue warning to provide general guidance for costs in applications at other locations within the Denver area.

B. Implementation Considerations

There are several important considerations related to successful planning and design of ATM. First, involvement and education of the public and local stakeholders is key for the successful planning and implementation of ATM treatments.

Second, the existing shoulder depth is a key piece of information needed to determine the feasibility of hard shoulder running. The best available data from CDOT was utilized in this study to determine the shoulder depths. However, prior to more detailed planning or design of this treatment, additional field investigations should be completed to determine if the existing shoulder depths support hard shoulder running or not.

Third, CDOT DTD is developing an algorithm based on speed and density to aid in determining the most appropriate variable speed for speed harmonization. This research should provide a scientific approach for modifying the freeway speeds.

Fourth, if ATM treatments are successfully installed on the initial pilot corridors, the application of treatments on the other corridors identified in **Table 4** should be considered. This might be possible in conjunction with other roadway improvement projects.

Finally, both the *CDOT Region 6 ITS Implementation Plan* and *Regional Intelligent Transportation Systems Architecture for the Denver Regional Area* should be utilized with any planning or design application of ATM within Denver. These two documents provide guidance to the implementation of ITS which is a key component to all of the ATM treatments discussed in this report. It is important that all future ATM projects and the equipment they utilize are in agreement with these two plans in order to assure a consistent application of both ITS and ATM throughout the region.

APPENDIX A ATM MARKET PACKAGES

Archived Data Mart (AD)

ITS Market Package

Purpose

AD1 - ITS Data Mart	Storing and logging of data for future use and data management
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Advanced Traveler Information Systems (ATIS)

ITS Market Package

Purpose

ATIS01 – Broadcast Traveler Information	Collect traffic conditions information and disseminate to public via cellular network or internet.
ATIS06 – Transportation Operations Data Sharing	Makes real-time transportation operations data available to transportation system operators for sharing.

Advanced Traffic Management Systems (ATMS)

ITS Market Package

Purpose

ATMS01 – Network Surveillance	Traffic detectors and CCTV transmit the collected data/video back to the CTMC and Region via the communications network.
ATMS02 – Traffic Probe Surveillance	Roadside Automatic Vehicle Identifiers (AVI) will retrieve toll tag transponder information using dedicated short range communications to provide traveler information and use of data in ATM algorithms.
ATMS04 - Freeway Control	Ramp metering, variable speed limits, and lane-use signals will be used to control traffic along the freeway. Also, will be used for the detection of incidents. Supports general advisory of travel condition to the roadway users. This is a key market package for ATM.
ATMS06 - Traffic Information Dissemination	Uses VMS and HAR to disseminate traffic and road conditions, closure and detour information, incident information, and emergency alerts and driver advisories.
ATMS07 - Regional Traffic Management	Provides for the sharing of traffic information and control among traffic management centers to support regional traffic management strategies, including coordination between freeway operations and arterial signal control within a corridor.
ATMS08 – Traffic Incident Management System	Manages both unexpected incidents and planned events to minimize impact to the transportation network. This market package includes incident detection capabilities through roadside surveillance devices (e.g., CCTV, AVI, MVRD, RMS, and ATRs) and through regional coordination at the TMCs. The coordination can also extend to Courtesy Patrol.
ATMS09 - Traffic Decision Support and Demand Management	Recommends courses of action to traffic operations personnel based on an assessment of current and forecast road network performance. This could be applied to speed harmonization, queue warning, and dynamic re-routing.
ATMS18 – Reversible Lane Management	I would suggest adding this because of lane control equipment used for dynamic demand changes even though we have no intention of doing anything reversible.

Emergency Management (EM)

ITS Market Package

Purpose

EM04 – Roadway Service Patrols	Supports roadway service patrol vehicles that monitor roads and aid motorists, offering rapid response to minor incidents (flat tire, accidents, out of gas) to minimize disruption to the traffic stream. Also supports vehicle dispatch to identified incident locations. Incident information collected by the service patrol is shared with traffic, maintenance and construction, and traveler information systems.
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APPENDIX B DETAILED CORRIDOR ANALYSIS TABLES

Candidate Corridor Active Traffic Management Treatments Detailed Tables

I-25 - US 36 to 120th	
Length (mi)	6.05
Volume (vpd)	119,000 to 174,000
Through Lanes	6 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	12 to 21
Width - Outside Shoulder NB (ft)	2 to 22
Width - Inside Shoulder SB (ft)	10 to 21
Width - Outside Shoulder SB (ft)	5 to 12
Full Depth Shoulder?	15.75" HMA NB and 14" PCCP + 6" ABC SB
Interchanges	120th (diamond), 104th (diamond), Thornton Pkwy (diamond), 84th Ave (diamond) & US 36 / I-270 (directional)
Right-of-Way (ft)	200 to 527
DRCOG Bottleneck?	Yes, Between 84th and US 36
Recent or future studies and construction projects	I-25 North PEL, 84th Reconstruction, 88th project
Potential ATM Opportunities	<p>Hard Shoulder Running - There is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles, however cross over points could be provided.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Hard Shoulder Running (possibly HOV hard shoulder), Speed Harmonization and Queue Warning

I-225 - I-25 to Parker	
Length (mi)	3.93
Volume (vpd)	109,000 to 128,000
Through Lanes	5 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	6 to 22
Width - Outside Shoulder NB (ft)	8 to 17
Width - Inside Shoulder SB (ft)	6 to 20
Width - Outside Shoulder SB (ft)	9 to 20
Full Depth Shoulder?	12" to 13" PCCP or 12" to 17" HMA
Interchanges	Parker (directional), Yosemite (diamond), DTC Blvd (diamond) & I-25 (directional)
Right-of-Way (ft)	200 to 300
DRCOG Bottleneck?	Yes, Yosemite to I-25
Recent or future studies and construction projects	TREX
Potential ATM Opportunities	<p>Hard Shoulder Running - Possible width limitation at DTC Blvd and weave between DTC Blvd and I-25 would make implementation very difficult. If these two items are addressed HSR could work.</p> <p>Speed Harmonization and Queue Warning- These treatments are feasible for this segment.</p>
Potential ATM Treatments	Hard Shoulder Running, Speed Harmonization and Queue Warning

C-470 - Wadsworth to I-25	
Length (mi)	12.3
Volume (vpd)	67,000 to 102,000
Through Lanes	4
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	4 to 6
Width - Outside Shoulder EB (ft)	7 to 21
Width - Inside Shoulder WB (ft)	4 to 7
Width - Outside Shoulder WB (ft)	6 to 14
Full Depth Shoulder?	2" SMA + 8" PCCP or 9" PCCP
Interchanges	Wadsworth (diamond), Platte Canyon (WB hook ramps), Santa Fe (diamond), Lucent (diamond), Broadway (diamond), University (diamond), Quebec (diamond), Yosemite (partial diamond) & I-25 (directional)
Right-of-Way (ft)	150 to 300
DRCOG Bottleneck?	Yes, east of Santa Fe and Yosemite to I-25
Recent or future studies and construction projects	Santa Fe interchange project
Potential ATM Opportunities	<p>Hard Shoulder Running - In general, shoulder widths are insufficient for HSR but could be widened to allow for this treatment.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment. In particular, queue warning could be implemented in the vicinity of the Santa Fe interchange.</p>
Potential ATM Treatments	Hard Should Running (with widened shoulders), Speed Harmonization and Queue Warning

US 6 - Kipling to Sheridan	
Length (mi)	3.01
Volume (vpd)	99,000 to 107,000
Through Lanes	6
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	2 to 4
Width - Outside Shoulder EB (ft)	1 to 15
Width - Inside Shoulder WB (ft)	2 to 4
Width - Outside Shoulder WB (ft)	1 to 15
Full Depth Shoulder?	Unknown
Interchanges	Kipling (partial clover), Garrison (diamond with CD road), Wadsworth (cloverleaf) & Sheridan (diamond)
Right-of-Way (ft)	110 to 300
DRCOG Bottleneck?	Yes, Wadsworth
Recent or future studies and construction projects	Wadsworth Reconstruction Study
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder depth is unknown and the widths are limited at major cross streets like Kipling, Garrison, Wadsworth and Sheridan. In addition, there is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

US 6 - Sheridan to I-25	
Length (mi)	2.14
Volume (vpd)	126,000
Through Lanes	5 to 7
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	2 to 4
Width - Outside Shoulder EB (ft)	2 to 20
Width - Inside Shoulder WB (ft)	2 to 4
Width - Outside Shoulder WB (ft)	2 to 13
Full Depth Shoulder?	Unknown
Interchanges	Sheridan (diamond), Knox (partial diamond), Federal (diamond) & I-25 (directional)
Right-of-Way (ft)	107 to 150
DRCOG Bottleneck?	Yes, Federal
Recent or future studies and construction projects	Valley Highway EIS (Federal to I-25) and US 6 over Bryant construction
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder depth is unknown and the widths are limited at major cross streets like Perry, Knox and Federal. In addition, there is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-25 - Lincoln to I-225	
Length (mi)	5.58
Volume (vpd)	181,000 to 221,000
Through Lanes	6 to 10
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	9
Width - Outside Shoulder NB (ft)	8 to 14
Width - Inside Shoulder SB (ft)	9
Width - Outside Shoulder SB (ft)	8 to 10
Full Depth Shoulder?	2" to 17.25" HMA
Interchanges	I-225 (directional), Belleview (diamond), Orchard (diamond), Arapahoe (partial clover), Dry Creek (diamond), County Line (partial clover) & C-470 (directional)
Right-of-Way (ft)	240 to 250
DRCOG Bottleneck?	No
Recent or future studies and construction projects	TRES segment
Potential ATM Opportunities	<p>Hard Shoulder Running - There is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles, however cross over points could be provided. The existing interchange spacing and auxiliary lanes along this segment could make HSR impractical.</p> <p>Speed Harmonization - This treatment is feasible for this segment.</p> <p>Queue Warning - This treatment would likely be most applicable in the vicinity of the Arapahoe / I-25 interchange.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-25 - I-225 to Broadway	
Length (mi)	7.08
Volume (vpd)	188,000 to 208,000
Through Lanes	8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	9
Width - Outside Shoulder NB (ft)	6 to 30
Width - Inside Shoulder SB (ft)	9
Width - Outside Shoulder SB (ft)	6 to 20
Full Depth Shoulder?	12" PCCP + 4" ABC or Variable HMA overlay
Interchanges	Broadway (diamond w/ hook ramps), Washington (Split diamond w/ CD road), Emerson (Split diamond w/ CD road), Downing (partial diamond), University (single point), Colorado (partial clover), Evans (diamond), Yale (diamond), Hampden (diamond) & I-225 (directional)
Right-of-Way (ft)	200 to 300
DRCOG Bottleneck?	No
Recent or future studies and construction projects	TRES segment
Potential ATM Opportunities	<p>Hard Shoulder Running - There is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles, however cross over points could be provided. The existing interchange spacing and auxiliary lanes along this segment could make HSR impractical.</p> <p>Speed Harmonization - This treatment is feasible for this segment.</p> <p>Queue Warning - This treatment would likely be most applicable in the vicinity of the Broadway / I-25 interchange.</p>
Potential ATM Treatments	Possibly Hard Shoulder Running, Speed Harmonization and Queue Warning

I-25 - I-70 to US 36	
Length (mi)	3.3
Volume (vpd)	177,000
Through Lanes	6 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	7 to 16
Width - Outside Shoulder NB (ft)	8 to 23
Width - Inside Shoulder SB (ft)	7 to 14
Width - Outside Shoulder SB (ft)	6 to 25
Full Depth Shoulder?	11.5" PCCP + 4" PMBB
Interchanges	US 36 / I-270 (directional), I-76 (directional), 58th (diamond) & I-70 (directional)
Right-of-Way (ft)	300 to 526
DRCOG Bottleneck?	No
Recent or future studies and construction projects	N/A
Potential ATM Opportunities	<p>Hard Shoulder Running - The widths are questionable at major cross streets like 58th. Also, there are multiple on and off ramps to / from major freeways in too short of a distance with HOV / HOT lanes as well.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-70 - Hwy 58 to I-25	
Length (mi)	8.72
Volume (vpd)	84,000 to 137,000
Through Lanes	4 to 12
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	4 to 14
Width - Outside Shoulder EB (ft)	2 to 10
Width - Inside Shoulder WB (ft)	4 to 10
Width - Outside Shoulder WB (ft)	4 to 24
Full Depth Shoulder?	7" to 12.75" HMA or 11" to 11.5" PCCP
Interchanges	Hwy 58 (directional), Ward (hook ramps), Kipling (diamond), Wadsworth / I-76 (directional), Harlan (diamond), Sheridan (partial clover), Lowell (partial diamond), Federal (diamond), Pecos (diamond) & I-25 (directional)
Right-of-Way (ft)	200 to 300
DRCOG Bottleneck?	No
Recent or future studies and construction projects	I-70 / Kipling EIS and Wadsworth reconstruction
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder widths are insufficient for HSR along the corridor and at the major crossings with Ward, Kipling, Harlan, Sheridan, Federal and Pecos. In addition, there is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-70 - I-25 to I-270	
Length (mi)	4.85
Volume (vpd)	118,000 to 137,000
Through Lanes	4 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	2 to 22
Width - Outside Shoulder EB (ft)	8 to 12
Width - Inside Shoulder WB (ft)	2 to 10
Width - Outside Shoulder WB (ft)	2 to 24
Full Depth Shoulder?	4" to 13.5" HMA
Interchanges	I-25 (directional), Washington (diamond), Brighton Blvd. (diamond), York (hook ramps), Steele (diamond), Colorado (partial clover), Monaco (diamond w/ CD road), Quebec (diamond) & I-270 (directional)
Right-of-Way (ft)	250
DRCOG Bottleneck?	Yes, between I-25 and York
Recent or future studies and construction projects	I-70 East EIS
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder widths are insufficient for HSR along the corridor due to the elevated nature of I-70. In addition, there is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-70 - I-270 to Pena Blvd	
Length (mi)	5.37
Volume (vpd)	98,000 to 183,000
Through Lanes	4 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	2 to 22
Width - Outside Shoulder EB (ft)	8 to 16
Width - Inside Shoulder WB (ft)	2 to 22
Width - Outside Shoulder WB (ft)	8 to 24
Full Depth Shoulder?	Unknown
Interchanges	I-270 (directional), Havana (partial clover), Peoria (diamond), I-225 (directional), Chambers (diamond) & Pena (directional)
Right-of-Way (ft)	250
DRCOG Bottleneck?	Yes, east of I-270 interchange
Recent or future studies and construction projects	I-70 East EIS (I-270 to Peoria), Central Park interchange
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder widths are insufficient for HSR along the corridor, primarily around the Havana structure. In addition, there is a concrete median barrier the length of the corridor which would prohibit cross over for emergency vehicles.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-270 - I-76 to I-70	
Length (mi)	5.99
Volume (vpd)	83,000 to 90,000
Through Lanes	4 to 6
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	4 to 30
Width - Outside Shoulder EB (ft)	8 to 15
Width - Inside Shoulder WB (ft)	6 to 30
Width - Outside Shoulder WB (ft)	8 to 15
Full Depth Shoulder?	12.5" to 13.5" PCCP or 3" to 13.5" HMA
Interchanges	I-76 (directional), York (diamond), Vasquez (cloverleaf), Quebec (unique) & I-270 (directional)
Right-of-Way (ft)	78 to 240
DRCOG Bottleneck?	Yes, Vasquez Blvd.
Recent or future studies and construction projects	N/A
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder widths are questionable at several locations along the corridor. In addition, the Vasquez / SH 6 / US 85 is a cloverleaf interchange which will not work with HSR.</p> <p>Speed Harmonization and Queue Warning - These treatments are feasible for this segment.</p>
Potential ATM Treatments	Speed Harmonization, Queue Warning

I-25 - Broadway to US 6	
Length (mi)	2.21
Volume (vpd)	206,000 to 222,000
Through Lanes	7 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	3 to 15
Width - Outside Shoulder NB (ft)	3 to 20
Width - Inside Shoulder SB (ft)	3 to 9
Width - Outside Shoulder SB (ft)	2 to 25
Full Depth Shoulder?	3" to 13.5" HMA
Interchanges	US 6 (directional), Alameda (diamond), Santa Fe (directional) & Broadway (diamond w/ hook ramps)
Right-of-Way (ft)	300
DRCOG Bottleneck?	Yes, Santa Fe / Alameda
Recent or future studies and construction projects	Valley Highway EIS, Alameda reconstruction and Santa Fe reconstruction
Potential ATM Opportunities	With the current and planned construction on this segment, Active Traffic Management likely will not be needed but could be reevaluated in the future if congestion persists.
Potential ATM Treatments	None since current construction should address problems but reevaluate in the future.

I-25 - US 6 to Colfax	
Length (mi)	1.09
Volume (vpd)	215,000
Through Lanes	8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	5
Width - Outside Shoulder NB (ft)	9 to 30
Width - Inside Shoulder SB (ft)	5
Width - Outside Shoulder SB (ft)	8 to 13
Full Depth Shoulder?	Unknown
Interchanges	Auraria / Colfax (directional), 8th (hook ramps) & US 6 (directional)
Right-of-Way (ft)	300
DRCOG Bottleneck?	No
Recent or future studies and construction projects	N/A
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder depths are questionable and the widths are not wide enough. It would also be difficult to incorporate HSR with the many existing ramp entrances / exits on I-25.</p> <p>Speed Harmonization and Queue Warning - Due to the tight interchange spacing and obstructed site lines due to existing bridges these treatments are not feasible for this segment.</p>
Potential ATM Treatments	None

I-25 - Colfax to 20th Street	
Length (mi)	1.78
Volume (vpd)	196,000 to 212,000
Through Lanes	8 to 10
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	5 to 9
Width - Outside Shoulder NB (ft)	4 to 20
Width - Inside Shoulder SB (ft)	5 to 9
Width - Outside Shoulder SB (ft)	7 to 22
Full Depth Shoulder?	Unknown
Interchanges	20th (diamond), Speer (partial clover), 23rd (diamond), 17th (hook ramps) & Auraria / Colfax (directional)
Right-of-Way (ft)	200 to 300
DRCOG Bottleneck?	Yes, between Speer and 20th
Recent or future studies and construction projects	15th Street and Speer bridge projects
Potential ATM Opportunities	<p style="text-align: center;">Hard Shoulder Running - The shoulder depths are questionable and the widths are not wide enough. It would also be difficult to incorporate HSR with the many existing ramp entrances / exits on I-25.</p> <p style="text-align: center;">Speed Harmonization and Queue Warning - Due to the tight interchange spacing and obstructed site lines due to existing bridges these treatments are not feasible for this segment.</p>
Potential ATM Treatments	None

I-25 - 20th Street to I-70	
Length (mi)	1.58
Volume (vpd)	253,000
Through Lanes	8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	7 to 17
Width - Outside Shoulder NB (ft)	6 to 12
Width - Inside Shoulder SB (ft)	7 to 10
Width - Outside Shoulder SB (ft)	10 to 22
Full Depth Shoulder?	Unknown
Interchanges	I-70 (directional), 38th (partial clover) & 20th (diamond)
Right-of-Way (ft)	300
DRCOG Bottleneck?	No
Recent or future studies and construction projects	N/A
Potential ATM Opportunities	<p>Hard Shoulder Running - The shoulder depths are questionable and the widths are not wide enough. It would also be difficult to incorporate HSR with the many existing ramp entrances / exits on I-25.</p> <p>Speed Harmonization and Queue Warning - Due to the tight interchange spacing and obstructed site lines due to existing bridges these treatments are not feasible for this segment.</p>
Potential ATM Treatments	None

US 36 - Just North of Wadsworth to Sheridan	
Length (mi)	5.27
Volume (vpd)	102,000
Through Lanes	4
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	9
Width - Outside Shoulder EB (ft)	7 to 17
Width - Inside Shoulder WB (ft)	9
Width - Outside Shoulder WB (ft)	9 to 13
Full Depth Shoulder?	Unknown
Interchanges	Wadsworth (diamond), 104th (diamond) & 92nd / Sheridan (diamond)
Right-of-Way (ft)	100 to 150
DRCOG Bottleneck?	Yes, between Interlocken and Wadsworth
Recent or future studies and construction projects	US 36 Corridor study
Potential ATM Opportunities	With the planned construction on this segment, Active Traffic Management likely will not be needed but could be reevaluated in the future if congestion persists.
Potential ATM Treatments	None due to proposed future construction which should address problems

US 36 - Sheridan to I-25	
Length (mi)	4.67
Volume (vpd)	117,000
Through Lanes	4 to 5
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	1 to 10
Width - Outside Shoulder EB (ft)	5 to 29
Width - Inside Shoulder WB (ft)	1 to 10
Width - Outside Shoulder WB (ft)	5 to 22
Full Depth Shoulder?	11" PCCP + 4" ABC or Variable depth HMA
Interchanges	92nd / Sheridan (diamond), Federal (partial clover), Pecos (diamond), Broadway (partial diamond) & I-25 (directional)
Right-of-Way (ft)	100
DRCOG Bottleneck?	No
Recent or future studies and construction projects	US 36 Corridor study
Potential ATM Opportunities	With the planned construction on this segment, Active Traffic Management likely will not be needed but could be reevaluated in the future if congestion persists.
Potential ATM Treatments	None due to proposed future construction which should address problems

I-225 - Parker to 6th Ave	
Length (mi)	5
Volume (vpd)	123,000
Through Lanes	4 to 6
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	2 to 34
Width - Outside Shoulder NB (ft)	10 to 18
Width - Inside Shoulder SB (ft)	2 to 25
Width - Outside Shoulder SB (ft)	6 to 21
Full Depth Shoulder?	5" to 12.5 " HMA or 12.5" to 13" PCCP
Interchanges	6th (diamond), Alameda (single point), Mississippi (diamond), Iliff (partial clover) & Parker (directional)
Right-of-Way (ft)	300
DRCOG Bottleneck?	Yes, 6th to Alameda and Yale to Parker
Recent or future studies and construction projects	FasTracks, 6th to Mississippi under construction and Mississippi to Parker under design for widening
Potential ATM Opportunities	With the planned construction on this segment, Active Traffic Management likely will not be needed but could be reevaluated in the future if congestion persists.
Potential ATM Treatments	None

I-225 - 6th Ave to I-70	
Length (mi)	3.48
Volume (vpd)	121,000 to 129,000
Through Lanes	4 to 8
Width - Through Lanes (ft)	12
Width - Inside Shoulder NB (ft)	10 to 22
Width - Outside Shoulder NB (ft)	10 to 30
Width - Inside Shoulder SB (ft)	11 to 31
Width - Outside Shoulder SB (ft)	11 to 29
Full Depth Shoulder?	12" PCCP
Interchanges	I-70 (directional), Colfax (diamond) and 6th (diamond)
Right-of-Way (ft)	300
DRCOG Bottleneck?	No
Recent or future studies and construction projects	FasTracks
Potential ATM Opportunities	With the planned construction on this segment, Active Traffic Management likely will not be needed but could be reevaluated in the future if congestion persists.
Potential ATM Treatments	None

C 470 - US 285 Interchange	
Length (mi)	1.07
Volume (vpd)	73,000
Through Lanes	4
Width - Through Lanes (ft)	12
Width - Inside Shoulder EB (ft)	4 to 7
Width - Outside Shoulder EB (ft)	6 to 13
Width - Inside Shoulder WB (ft)	4 to 6
Width - Outside Shoulder WB (ft)	6 to 20
Full Depth Shoulder?	Unknown
Interchanges	US 285 (partial clover)
Right-of-Way (ft)	400 to 550
DRCOG Bottleneck?	Yes
Recent or future studies and construction projects	N/A
Potential ATM Opportunities	Due to the nature of the problem at this interchange, weaving related to the partial clover layout, none of the ATM treatments are applicable.
Potential ATM Treatments	None