Appendix E

Study Recommendations (TDM Tech Memo, ITS/AV/CV Tech Memo, Other Study Recommendations Summary)

JACOBS

MEMO

TO:	I-70 PEL Study Project File	**DATE:**	August 2018
FROM:	Jacobs Engineering		
SUBJECT:	Travel Demand Management (TDM) Technical Memorandum		

This technical memorandum was prepared in support of the I-70 Planning and Environmental Linkages (PEL) Study Report prepared for the Missouri Department of Transportation (MoDOT). This memorandum summarizes Transportation Demand Management (TDM) measures currently being used in the State of Missouri and the St. Louis region, and identifies additional measures that may be implemented in the I-70 PEL Study Corridor. The information provided here will inform the development of a TDM Plan for the Study Corridor that will identify TDM projects, implementation opportunities, and funding timelines.

References, acronyms, and abbreviations are listed at the end of this memorandum.

1 What is TDM?

Transportation Demand Management (TDM) refers to strategies that increase the efficiency of the transportation system through low-cost, high-efficiency transportation solutions. TDM includes a wide range of strategies such as carpooling, vanpooling, transit, bicycling, and walking. Strategies also include employer-based incentive programs, such as alternative work schedules that shift travel demand from peak travel times, and teleworking that reduces or eliminates the need for trips. In addition to improving travel reliability, TDM strategies can also extend the useful life of a transportation facility, reduce fuel consumption, and improve air quality.

2 Existing State, Regional, and Local TDM Strategies

This section summarizes TDM strategies currently in place at the state level and at the local level within the Study Area.

2.1 RideFinders Carpooling and Vanpooling Services

With the goal to improve air quality and reduce traffic congestion, MoDOT has partnered with RideFinders to provide a free carpool and vanpool ride matching service for commuters in the St. Louis region. This service operates in the City of St. Louis, St. Louis County, St. Charles County, and other counties in the region. RideFinders also offers a Guaranteed Ride Home Program that provides four free taxi rides home annually (RideFinders 2018).

2.2 Commuter Parking Lots

MoDOT provides the location of their 30 commuter parking lots in the St. Louis metropolitan area through an online interactive Traveler Information Map (http://traveler.modot.org/map/). MoDOT maintains these lots to provide convenient parking for commuters and encourage alternate commuting options, such as carpooling, van pooling, and transit (MoDOT 2018a).

2.3 "Project Real-time" and Traveler Information

MoDOT has traffic cameras at locations around the state that feed into an online website to provide drivers with real time images and information about road and traffic conditions (http://traveler.modot.org/map/). MoDOT also provides this information via dynamic video message boards along roadways and on their website. This TDM strategy allows drivers to consider other modes of transportation, alternate routes, and/or different travel times based on current conditions (MoDOT 2018b).

2.4 Bike Share

The City of St. Louis has partnered with LimeBike and Ofo to provide a dockless bike sharing service within the city limits. Traditionally, bike share programs require bike docking stations and kiosks and provide only a limited number of bikes to share. A dockless bike share service uses bicycles equipped with GPS and a locking mechanism on the back wheel. Using smartphone technology, users can locate bicycles, unlock them, and drop them off at any location within city limits ready for the next user. The program recently expanded to include shared electric scooters and eventually will include electric bicycles. The intent of this program is to make bike sharing an alternative mode of transportation that is easy to use and readily available (St. Louis Post-Dispatch 2018).

2.5 St. Louis County Road Diet Policy

St. Louis County has implemented a road diet policy for county-maintained multilane roadways. A road diet is defined as reducing the number of travel lanes to accommodate a two-way left-turn lane, alternate transportation modes (such as walking or bicycling), or on-street parking. In most cases, implementing a road diet involves modifying pavement markings. In St. Louis County, this policy is more tailored to accommodate bicycling and pedestrian travel (St. Louis County 2016).

2.6 East-West Gateway Council of Governments (EWG) Congestion Management Process and Policies

The federal Congestion Mitigation and Air Quality (CMAQ) Improvement Program helps state and local governments meet the requirements of the Clean Air Act by providing funding for transportation related projects that will improve air quality and relieve congestion. Administered by the Federal Highway Administration, the CMAQ program was created in 1991 and has been reauthorized under successive Transportation Bills including the FAST Act in 2015. As required under the CMAQ, the EWG developed a Congestion Management Process that outlines policies and strategies to integrate congestion management in their planning and programming practices to better achieve the goals of reducing congestion, improving reliability, and increasing multi-modal transportation use for the transportation system in the St. Louis region (EWG 2013). Federal requirements specifically state that, "…federal funds may not be programmed for any project that will result in a significant increase in the carrying capacity for single-occupancy vehicles (SOVs) (i.e., a new general purpose highway on a new location or adding general purpose lanes), with the exception of safety improvements or the elimination of bottlenecks…"

2.7 Reduced Fares Program

Metro St. Louis Transit services provides discounted fares to eligible riders with the goal to encourage transit use by providing low-cost options. Table 1 summarizes these reduced fare programs (Metro St. Louis 2018).

Table 1: Metro St. Louis Reduced Fare and Passes Programs

Fare/Pass Type	Rider Eligibility
Student Semester Pass	Full-time students, age 23 and younger, who attend a college or university within the Metro service area are eligible to purchase a Metro "Student Semester Pass" at a reduced price.
Metro U-Pass	Select colleges/universities offer unlimited rides on MetroBus and MetroLink through the customized Metro University Pass (U-Pass), where the school pays for all or part of the transit pass for students and faculty.
Senior Reduced Fair Permits	Metro Senior Permits allow seniors, age 65 or older, to ride MetroBus and MetroLink at a reduced price.
Reduced Fare for Individuals with Disabilities	Qualified individuals with disabilities receive reduced fares for MetroBus, MetroLink, and/or Metro Call-A-Ride services.
Commuter Advantage Program	Allows employers to offer the cost of a transit pass to employees on a pre-tax basis.
Gateway Go Card	Allows individuals aged 13 to 25 to purchase tickets at a reduced price during the summer to provide an easy and affordable option to commute to summer jobs, summer camps, and other personal and professional development opportunities.

2.8 Safe Trek

Metro St. Louis Transit services provides Safe Trek, a smartphone application for commuters to use in the event of an emergency when commuting on the Metro system, while waiting for MetroLink and MetroBus vehicles at Metro Transit Centers, or while waiting or walking to the bus stop or MetroLink station. Because a common perception is that public transit is unsafe due to crime, the intent of Safe Trek is to increase Metro Transit ridership by helping riders feel safer (Metro St. Louis 2018).

3 Additional TDM Strategies Applicable to the Study Area

This section describes TDM strategies that are not currently in place at the state or local level but would improve the overall efficiency of the transportation system in the Study Area. These measures are organized by Public Policy/Regulatory Strategies, Public Mode Support Strategies, Employer/Institution Based Strategies, and Pricing Strategies.

Table 2 summarizes TDM strategies applicable to the Study Area and identifies the application market area, timeframe to implement, enabling authority, and implementing authority for each strategy, as defined below:

- Application Market Area: The application/market area characterizes the target market to which the strategy can be applied. Target markets are identified by their context, which includes geographic indicators, densities, types of development, type of facility, type of commuting travel, and/or time of day (peak vs. off-peak). Strategies must be applied to appropriate markets to be effective and visible.

- Timeframe to Implement: This term identifies the approximate term within which a TDM strategy could be implemented. Strategies are identified as requiring a short time period (less than two years), a medium time period (two to five years), or a long time period (more than five years). Implementation time does not correspond to the time needed to bring about behavior changes.
- Enabling Authority: The agency (or agencies) responsible for introducing, enabling, or mandating each measure.
- Implementing Authority: The agency (or agencies) responsible to put the strategy in place, and administer, operate or enforce the TDM measures.

Table 2: TDM Strategies Applicable to the Study Area

TDM Strategy	Application Market Area	Timeframe to Implement	Enabling Authority				Implementing Authority				
			State	Region	City/County	Transportation Agency	State	Region	City/County	Transportation Agency	Employer
Public Policy/Regulatory Strategies											
Parking Restrictions	Dense urban areas and high traffic destinations	Short			X				X	X	
Trip Reduction Ordinances	To and from dense urban areas and high traffic destinations	Short			X				X		X
HOV Lanes	Congested corridors	Medium-Long	X			X	X		X		
Public Mode Support Strategies											
School-pooling	All markets	Short			X				X		
Bike to Work Day	All markets	Short	X				X				X
Predictive Traveler Information	All markets	Short	X		X		X				
Dynamic Ridesharing/ Priced Vehicle Sharing	To and from dense urban areas and high traffic destinations	Short		X	X			X	X		
On-Demand Transit	Dense urban areas and high traffic destinations	Short			X	X		X	X		

Table 2: TDM Strategies Applicable to the Study Area

TDM Strategy	Application Market Area	Timeframe to Implement	Enabling Authority				Implementing Authority				
			State	Region	City/County	Transportation Agency	State	Region	City/County	Transportation Agency	Employer
Employer/Institution Based Strategies											
Employer and Campus TDM	Multi-employer campuses and education institutions	Short									X
Flexible Work Arrangements	All markets	Medium		X	X						X
Pricing Strategies											
Tolling and Dynamic Tolling	Congested corridors	Medium-Long	X		X		X		X		
HOT Lanes	Congested corridors	Medium-Long	X		X		X		X	X	
Zone Pricing	Congested Corridors	Medium-Long	X		X		X		X	X	
Dynamically Priced Parking, Parking Cash-Out	Dense urban areas and high traffic destinations	Short	X		X				X		X

3.1 Public Policy/Regulatory Strategies

Public policy/regulatory strategies incorporate restrictions and regulations to auto use and provide political support and guidance to new institutional relationships. Restrictions and regulations can be implemented at the state, regional, or local level.

3.1.1 Parking Restrictions

To reduce the number of vehicles in a specific area or corridor, parking restrictions limit the amount of public parking available. This can be implemented through zoning ordinances that decrease private parking required per residential unit or private parking by commercial square footage; by restricting public parking to residents only; by restricting time available to occupy parking; or by restricting parking available by time of day. The City of Boston has restricted much of the free on-street parking in downtown residential areas to residents only, has lowered parking meter time limits, and has increased the fines for all parking violations. These measures aim to discourage suburban drivers from commuting into downtown via automobiles, especially single-occupancy autos (City of Boston 2018).

3.1.2 Trip Reduction Ordinances (TRO)

A TRO is an authoritative order implemented at the city or county level that requires developers, employers, and/or transportation associations/districts to implement TDM and congestion management techniques. This strategy is best applied to large metropolitan areas with surrounding suburbs. These areas tend to generate high trip frequency due to high population, employment, and activity centers. The goal of a TRO is to reduce SOV trips through the use of transit and carpool options. Places such as Santa Monica, California and the State of Massachusetts have implemented tiered requirements, based on the number of employees, that require employers to develop and apply a TDM workplan (ABC 2014).

3.1.3 HOV Lane Policy

A high-occupancy vehicle (HOV) lane, sometimes called a carpool lane, is a special lane reserved for the use of carpools, vanpools, and buses. Such lanes are usually located adjacent to the general purpose or unrestricted lanes. HOV lanes enable those who carpool or ride the bus to bypass traffic in adjacent general purpose lanes. After implementing HOV lanes on three routes in Dallas, Texas, the city observed increases in automobile occupancy (number of people occupying a single vehicle) by eight percent on all freeways. Additionally, between the three corridors where HOV lanes have been implemented (I-30, I-35 Eastbound, and I-635), a significant increase in carpooling has occurred, ranging from 79 percent to 296 percent. Travelers who use the HOV lanes are saving at least five minutes on their trips (University of Utah 2005).

These lanes may be restricted to HOV users at all times or during peak travel periods (depending on location). HOV lanes help improve the efficiency of the transportation system by restricting or limiting access to SOVs and giving priority to ridesharing and transit, providing a travel time incentive for users of these (DRCOG 2012).

3.2 Public Mode Support Strategies

Public mode support strategies focus on publicly provided alternatives to SOV travel, and services and facilities that encourage and support alternate modes of transportation.

3.2.1 Bike-to-Work Day

Bike-to-Work Day is a nationally celebrated annual event in which biking is promoted as an alternative commuter mode. The event seeks to increase bike commutes by providing new and occasional bike commuters with resources such as customized bike route and bike safety information. Bike-to-Work Day is currently led by the Trailnet organization (https://trailnet.org/) with local sponsorship, marketing, leadership, and management partnered between the metropolitan planning organization, department of transportation, local and regional bicycle agencies, and bicycle retailers and shops. The intent of Bike-to-Work Day is to improve air quality and reduce SOV use and congestion.

3.2.2 Predictive Traveler Information

This strategy uses real-time and historical transportation data to predict upcoming travel conditions and convey that information to travelers pre-trip and en-route (such as in advance of strategic route choice locations) in an effort to influence travel behavior. Predictive traveler information is incorporated into a variety of traveler information mechanisms (e.g., multi-modal trip planning systems, 511 systems, and dynamic message signs). The use of predictive traveler information can reduce trips during peak travel periods and improve efficiency of the transportation system through the use of alternate routes. To assist traveler trip and route selection, the Colorado Department of Transportation (CDOT) provides real time information to travelers through dynamic message signs, mobile applications and alerts, dial in options, and AM/FM radio.

3.2.3 Dynamic Ridesharing/Priced Vehicle Sharing

Dynamic Ridesharing allows travelers using advanced technologies, such as smart phones and social networks, to arrange a short-notice, one-time, shared ride. This facilitates real-time and dynamic carpooling to reduce the number of auto trips/vehicles trying to use already congested roadways. Priced dynamic ridesharing adds the element of cost sharing.

Priced vehicle sharing involves providing vehicles, typically by a commercial vendor, for use by members in exchange for an hourly or daily charge. The periodic rates for use can be fixed or can vary in response to demand. Customers have the advantage of using the vehicle only when needed and can avoid owning a car or reduce the number of cars in a family.

3.2.4 On Demand Transit

This strategy allows travelers to make real-time trip requests for services with flexible routes and schedules. It allows users to request a specific transit trip based on their individual trip origin/destination and desired departure or arrival time. Through service providers, including UberPool, LyftLine, and Chariot, this strategy is being used and/or tested in numerous metro areas, such as New York City, Boston, Chicago, Washington DC, the San Francisco Bay Area, and St. Louis. Downtown STL, the St. Louis downtown business association, conducted a four-month pilot study in 2018 offering free, on-demand shuttle rides with the intent of providing "first mile" and "last mile" service.

3.3 Employer/Institution Based Strategies

These strategies consist of private sector programs and services that encourage employees to change their commuting patterns. Strategies include incentives to make publicly provided modes more attractive, disincentives to solitary commuting, flexibility in work location and schedule, and employer management policies that provide employees with mode choice flexibility.

3.3.1 Employer and Campus TDM

Large employer sites, campuses, or business parks can encourage employee transit use by offering transit passes, and offering first- and last-mile options for transit users by providing improved pedestrian access, bicycle access and storage, and on demand shuttle services. Reducing employee SOV trips can in turn reduce on-site parking demand, congestion, and facility costs.

3.3.2 Flexible Work Arrangements

Flexible work arrangements are strategies that reduce the number of vehicles on the road during rush-hour traffic by allowing employees to alter when and where they do their work. Some strategies, like compressed work-week scheduling and flextime, reduce traffic by encouraging employees to commute to work when the roads are less congested. Other strategies, like telecommuting or alternative work locations, can potentially eliminate commute trips altogether.

3.3.3 Alternative Work Hours

Alternative work hours allow employees to work the typical five, eight-hour days each week and allow them to choose their arrival, departure, and break times, within limits set by management, to accommodate personal obligations and avoid peak traffic hours. Typically, a core business time is established in which all employees are required to be present.

3.3.4 Compressed Workweek

A compressed workweek involves employees working more than the typical eight hours per day, resulting in fewer days worked each week and/or month. Typical compressed workweeks include a 9-80 schedule (working 80 hours over 9 work days with one day off every two weeks) or a 4-10 schedule (working 40 hours over 4 work days with one day off each week).

Compressed workweeks reduce employee travel time by eliminating up to two commute trips a week while also reducing overall travel time because the commute is shifted to non-peak periods. The earlier start time and later end time often allow employees to avoid traffic by traveling before and after the typical commute congestion occurs.

3.3.5 Teleworking

Teleworking allows employees to work from places outside their designated office for convenience and travel time reductions. Teleworkers communicate with colleagues via technology. Many variations of telecommuting exist, but the most common form is working from home using a company computer that connects to the workplace's electronic server. A core business time or day can be established in which employees are required to be present.

3.4 Pricing Strategies[1]

Pricing Strategies are pricing structures that affect the cost of transportation. These strategies provide monetary disincentives or incentives to some travel behavior with the intent to encourage other modes outside of SOVs.

3.4.1 Tolling and Dynamic Tolling

Tolling (fixed or variable rate) is the act of charging a driver a fee for use of a privately or publicly built road, bridge, or tunnel. Toll rates on most of the existing facilities in the United States (U.S.) are fixed, meaning they do not vary by time or day of usage. Use of variable and dynamic tolls is increasing in the U.S. Variable tolls change in response to anticipated traffic conditions based on a fixed schedule. Dynamic tolls change in response to congestion levels based on real-time traffic conditions. Dynamic tolling lanes implemented in the State of Virginia on the I-95 Corridor between Fredericksburg and Springfield have proven to lower travel times in the most congested areas of the corridor by 12 minutes while increasing the overall average speed across the entire corridor (FAMPO 2015).

3.4.2 HOT Lanes

High-Occupancy Toll (HOT) lanes are similar to HOV lanes; however, they allow SOVs to pay a fee for use of the facility. Rates for using HOT lanes can be fixed price or can dynamically change based on the level of congestion on the general-purpose lanes. HOT lanes encourage ridesharing and transit use by providing these modes with free use of these lanes, which typically offer higher travel speeds and increase reliability of travel times (DRCOG 2012). The Florida Department of Transportation (FDOT)

[1] As of August 2018, the State of Missouri did not have legislation that allows new toll facilities or tolling of existing facilities.

converted HOV lanes to HOT lanes on the I-95 corridor in Miami, Florida. Transit, registered carpools of three or more travelers, hybrid vehicles, motorcycles, and vanpool services were exempted from tolls. As a result, FDOT saw increases in ridesharing and carpooling in the corridor (FDOT 2018).

3.4.3 Zone Pricing

In zone pricing, a driver pays a toll when entering a "zone." The zone toll can be fixed or can change dynamically based on time of day and/or day of the week. Zone pricing is currently employed in a number of cities worldwide, including Singapore and London. Cities that employ zone pricing have reported decreased congestion, decreased vehicle trips, and an increase in transit ridership (FHWA 2008). The zone pricing program implemented in London, England includes congestion zones in the city center, for which motorists pay a fee to enter during peak traffic periods. To support alternatives to travel in congestion zones, the city established park and ride spaces, introduced new bus routes, and increased bus frequency in and around zones. Despite a 20 percent population growth in population since 2000 near congestion zones, the city has observed a nine percent reduction in traffic volume and a 16 percent reduction in carbon emissions (TSTC 2018).

3.4.4 Dynamically Priced Parking and Parking Cash Out.

Downtown areas where there is an abundance of on-street parking (paid or free) encourage more automobile trips. This abundance of on-street parking also uses portions of streets that could be used for the flow of traffic.

A dynamically priced parking strategy involves parking fees that are actively varied based on demand and availability to influence trip timing choice and parking facility or location choice. The goal of this strategy is to more efficiently balance parking supply and demand, reduce the negative impacts of travelers searching for parking, or to reduce traffic impacts associated with peak period trip making. In 2010, San Francisco, California initiated SFpark, a federally-funded pilot project to test demand-based pricing. The city implemented new parking rates accompanied with off-peak discounts in public garages, and installed occupancy sensors and new smart meters with extended time limits. This resulted in decreases in average hourly prices, a 23 percent decline in citations issued to parking violators, a 43 percent decline in the time drivers spent searching for parking, and a 30 percent decrease in greenhouse emissions in the pilot's project area (PBOT 2015).

Parking cash out applies to employers who pay for their employee's parking cost. The program involves payments to employees who do not require a parking space by choosing to travel to work in a mode other than an automobile. Employees who chose to continue to accept their free/subsidized parking can continue to do so; however, the parking cash out encourages walking, bicycling, and/or transit use.

4 TDM Strategies on I-70

Based on a review of the issues affecting each segment of the I-70 PEL, the following table presents segment specific TDM strategies that are not currently employed but could provide benefits to I-70 operations without requiring additional construction.

Table 3: Recommended TDM Strategies on I-70

TDM Strategy	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Comments
Parking Restrictions					X	Effective in reducing SOV trips into high density employment centers. Would require City of St. Louis to change parking ordinances.
Trip Reduction Ordinances				X	X	Would be very difficult to enact given current political conditions. Would require city and/or county acceptance and ordinance changes.
HOV Lane	X	X	X	X	X	Would be unpopular with most SOV travelers given the high number of single occupancy trips.
Predictive Traveler Information	X	X	X	X	X	Could use historical MoDOT travel time data for I-1-70 to compare current trip time versus average trip time.
Dynamic Ridesharing			X	X	X	Equivalent to Uber/Lyft rideshare options.
Employer and Campus TDM	X	X	X			Effective when main office/campus is in high density employment centers such as downtown St. Louis. Open a satellite office in St. Charles County or far western St. Louis County for employees/students to use. Current examples would include University of Missouri-St. Louis (UMSL), Lindenwood University, Washington University, and BJC Healthcare, which all have satellite locations.
Flexible Work Arrangements	X	X	X	X	X	Allowing employees to telecommute or work flexible schedules would remove vehicles from I-70 during certain days and/or times. Would require employer flexibility.
Tolling and Dynamic Tolling			X	X	X	No current legislation allowing tolling. Most effective in congested sections of I-70.
HOT Lanes	X	X	X	X	X	Recommended for consideration if mainline capacity improvements are proposed. No current legislation allows tolling. Would be unpopular with SOV travelers.
Zone Pricing					X	No current legislation allows tolling. Effective in reducing SOV trips into high density employment centers.
Dynamically Priced Parking					X	Effective in reducing SOV trips into high density employment centers. Would require City of St. Louis to upgrade all parking meters, which is costly.

TDM strategies that are not expected to have an appreciable effect on SOVs using I-70 include School-Pooling, Bike to Work Day, and On-Demand Transit.

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6 Abbreviations and Acronyms

Acronym or Abbreviation	Definition
ABC	A Better City
CDOT	Colorado Department of Transportation
CMAQ	Congestion Mitigation and Air Quality
DRCOG	Denver Regional Council of Governments
EWG	East West Gateway Council of Governments
FAMPO	Fredericksburg Area Metropolitan Planning Organization
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle
MoDOT	Missouri Department of Transportation
PBOT	Portland Bureau of Transportation
PEL	Planning and Environmental Linkages
SOV	Single-Occupancy Vehicle
TDM	Transportation Demand Management

TRO	Trip Reduction Ordinances
TSTC	Tri-State Transportation Campaign
UMSL	University of Missouri-St. Louis
U.S. or US	United States

JACOBS

MEMO

TO:	I-70 PEL Study Project File	**DATE:**	July 2018
FROM:	Jacobs Engineering		
SUBJECT:	Intelligent Transportation Systems (ITS) and Autonomous and Connected Vehicle (AV/CV) Investment Strategies Technical Memorandum		

This technical memorandum discusses Intelligent Transportation Systems (ITS), autonomous vehicle (AV) and connected vehicle (CV) technologies, and makes recommendations for implementing these technologies in the I-70 Planning and Environmental Linkages (PEL) Study Corridor. While predictions about the timeframe for adopting AV/CV technology vary greatly, the Missouri Department of Transportation (MoDOT) and the East West Gateway Council of Governments (EWG) have begun to consider these technology advancements as part of their long-range transportation planning processes, as found in the *St. Louis Region ITS Architecture Executive Summary* (EWG 2015), the *St. Louis Region Emerging Transportation Technology Strategic Plan* (EWG 2017), and the *2018 Long Range Transportation Plan Update* (MoDOT 2018). The recommendations in this memorandum build on the recommendations of these plans, which are summarized herein.

This memorandum starts by introducing ITS and CV/AV initiatives and discussing previous work outlined in regional planning documents. It then discusses the value of technology investments in the context of the Purpose and Need statement for the PEL Study Corridor. Lastly, it breaks out recommendations in the near-, mid-, and long-term time horizons for MoDOT to strategically roll-out technology to assist in managing traffic safety and mobility issues along the I-70 corridor.

References, acronyms, and abbreviations are listed at the end of this memorandum.

1 Introduction to ITS and CV/AV Initiatives

1.1 History and Vision

The transportation industry is in a state of change. While the transportation system has relied heavily on steel and concrete to improve and expand transportation services, capital costs and right-of-way limitations have made these improvements costlier in terms of economic, social, and political impacts. As a result, transportation agencies have begun to supplement infrastructure improvement strategies with alternatives that can help manage travel demand and operations. The use of relatively low-cost technology to improve roadway operations has supported these initiatives, allowing agencies to launch large-scale monitoring and information distribution systems that can be used to manage and optimize the efficiency of the transportation system.

Transportation agencies throughout the United States (U.S.) have supported ITS for over 20 years. Many studies have shown that implementing ITS programs improves safety and mobility. The installation and maintenance costs of an ITS program tend to be lower than traditional infrastructure improvements, such as adding lanes. As such, well-designed ITS programs tend to have good benefit-cost ratios and are becoming a preferred tool used by agencies to help to address safety or mobility issues.

Considering the advancements in wireless communication technology, state and federal agencies have been further exploring opportunities to leverage technology more effectively. The concept of CV technology would be one such system, where an onboard transceiver imbedded in the vehicle or the use of other communication devices such as a smartphone would transmit position and directional data to other vehicles in the area. Communicating vehicles would be able to detect each other through wireless communications, even when visually obstructed. The onboard transceivers also could communicate with roadside transceiver units that are linked to a transportation agency's communications network. This would allow vehicles to share local travel information with the agency, thereby allowing the agency to share broader travel information from the region. The goal of a CV program is to create a nationwide driving environment, with safety and mobility information exchanged in almost real-time, significantly reducing the number of avoidable crashes and providing more efficient route selection.

Automobile manufacturers also have been working toward the development of an autonomous vehicle, which is a vehicle that shifts some or all of the driving responsibilities from the human driver to a computer. Such a system represents a complete evolution in the way a transportation system operates, triggering long-term changes in engineering standards and traffic operations. Some autonomous features are present in today's vehicles, such as lane departure assistance and adaptive cruise control. Over the next few decades, vehicles will continue to incrementally gain autonomous features, changing the road's operational environment as human driving becomes less necessary and less common.

Because these innovations are being developed and their deployment is imminent, transportation agencies have started planning for a transportation system that will be dramatically different from what exists today. While not knowing the standards required in the future makes it challenging to plan for such a system today, many prerequisite investments for advanced ITS programs, CVs, and AVs can be anticipated.

2 Planning Studies and Strategies

As noted earlier, MoDOT and EWG have begun to identify relevant technology initiatives. Technology recommendations from MoDOT and EWG transportation plans are summarized in the following sections.

2.1 St. Louis Regional ITS Architecture – Executive Summary (EWG 2015)

This plan outlines future deployment of ITS in the St Louis region. The plan created three tiers of incremental initiatives required to deploy a "responsive and real-time" transportation system. ITS system deployment initiatives in this plan related to AV/CV readiness are summarized in Table 1. Existing ITS technology currently being employed on I-70 is discussed below.

Table 1: EWG's ITS Strategies and Recommendations

Tier	Initiatives
Tier 1	• Standardize platform of data and video exchange, regional fiber, and new wireless components across the region. • Implement real-time incident data feeds for sharing with regional partners. • Implement real-time traffic data feeds, traffic signal status feeds, and video feeds or sharing with regional partners
Tier 2	• Incorporate adaptive and real-time response traffic management technology including ramp metering, dynamic queue warning, and adaptive signal control on adjoining and/or parallel arterials.
Tier 3	• Install new or additional roadside closed-circuit television (CCTV) cameras, traffic detection equipment, dynamic message signs, road weather information systems, fiber optic communication networks coordinated traffic signals, and Bluetooth or other sensors.

2.2 St. Louis Region Emerging Transportation Technology Strategic Plan, EWG 2017

This plan addresses emerging technologies in the transportation industry and identifies strategic goals. Strengths, weaknesses, opportunities, and threats are analyzed to identify policies, programs, and actions regarding technology and its potential impacts in the St. Louis region. Plan recommendations related to AV/CV readiness are summarized in Table 2.

Table 2: EWG's AV/CV Strategies and Recommendations

Policy Area	Policy Purpose	Policy Description
Safety	Crash avoidance	Invest in vehicle-to-infrastructure (V2I) communications infrastructure to support safety applications for drivers and pedestrians.
Information Management	Privacy	Adopt standards to ensure systems and technologies incorporate data privacy, specifically those related to personally identifiable information.
	Cybersecurity	Support funding to increase investment in cybersecurity of transportation networks, particularly as new technology is deployed.
System Management and Operations	ITS needs	Evolve ITS and congestion management planning in the region to integrate and adjust technology applications as vehicle technologies continue to advance.
	Active system management	Implement active system management strategies, such as Integrated Corridor Management, leveraging technologies. Active management also includes improved regional operational collaboration and systems to optimize performance.

Table 2: EWG's AV/CV Strategies and Recommendations

Policy Area	Policy Purpose	Policy Description
	Infrastructure capacity and needs	Identify potential changes in infrastructure, such as reduced lane widths, opportunities for dynamic use of shoulders, and other strategies. Explore and consider the future potential for development of AV-designated lanes (especially if technology doesn't mature as anticipated such that AVs can only operate in certain conditions), truck-only lanes, and other infrastructure-related changes to support technologies that improve safety and reliability, and to incentivize use of advanced vehicle technologies.
	Data sharing	Ensure data feeds are provided to help the private sector and the public have access to real-time information.
Efficient Shipping and routing	Prioritization	Prioritize freight corridors when outfitting roads with necessary CV/AV technologies.
Pilot Testing and Research	Pilot testing	Cooperate in tests of autonomous and connected vehicle technology for freight systems by having a clear process for permitting pilot programs and tests.
Infrastructure Preservation and Maintenance	Conditions monitoring	Evaluate the use of advanced technologies to support monitoring conditions, including potential for use of drones and vehicle-generated data.
	Investments	Work with state departments of transportation (DOTs) partners to explore use of new technology within the physical infrastructure itself, such as use of advanced pavements and integration of communications technology in infrastructure. Build on research programs and pilot deployments available from the U.S. DOT.

2.3 2018 Long Range Transportation Plan Update (MoDOT 2018)

This plan establishes goals and objectives to achieve an overall plan to address Missouri's transportation needs and demands. It addresses infrastructure readiness, policy and planning, liability concerns, infrastructure funding, and maintenance. Specific to AV/CV, the plan addresses AV/CV technology, including concerns related to the uncertain future of transportation technology, perceived concerns of AV/CV technologies, and the possible effects of AV/CV technology and how it could change the needs of capital spending to accommodate these innovations. The plan also identifies key infrastructure changes needed in the Missouri transportation system to facilitate implementation of these new technologies, which are summarized in Table 3.

Table 3: MoDOT Recommendations for Key Infrastructure Changes

Functional Area	Action
Maintenance	• Improve striping. • Improve sign visibility/readability.
Operations/Construction/ Design	• Provide reliable network communications between all infrastructure assets. • Invest in advanced communication network.
Construction/ maintenance/ operations	• Inventory and communicate work zones and Maintenance of Traffic (MOT) plans precisely to vehicles.

Table 3: MoDOT Recommendations for Key Infrastructure Changes

Functional Area	Action
Design/construction	• Consider pavement design standards for rutting (AVs may be more consistent in lane placement and, therefore, increase wear on select pavement sections). • Consider safety zones/shoulder availability to allow for an AV safety fall back state to pull over if there is a minor malfunction. This reduces impact of failures or crashes. • Separate AV lanes to increase efficiency and to use less right-of-way with narrower lanes. • Provide barrier separation or broadcast pedestrian and bicycle locations to increase the detection and reaction time for AVs when interacting with vulnerable road users. • Consider altered geometry. AVs and CVs can react faster, which alters effective stopping sight distance as well as merging and weaving distances.
Planning	• Implement roadway classifications. Build upon the road classification system developed by Colorado DOT and expand its potential for use nationally.

2.4 U.S. Department of Transportation Policy and Planning for New Technologies

In September 2017, the U.S. Department of Transportation (U.S. DOT) National Highway Traffic Safety Administration (NHTSA) prepared a presentation entitled, *Automated Driving Systems 2.0: A Vision for Safety* that outlines a non-regulatory approach to AV technology safety. It provides guidance to support the automotive industry and other key stakeholders in establishing best practices for the testing and safe deployment of automated driving systems (ADSs), delineates federal and state roles in regulating ADSs, and provides a framework for states to develop procedures and conditions for the safe operation of ADSs on public roadways. Key recommendations from the presentation are summarized below:

- Focus roadway technology integration to address levels 3-5 Automated Driving Systems (ADS) as defined by the Society of Automotive Engineers (SAE) Autonomy Levels (see Appendix A).
- Encourage public disclosure of voluntary safety self-assessments of new technology integration and/or pilots. However, there are currently no compliance requirements or enforcement mechanisms in place; no waiting period or delay to begin testing or deployment of roadway technology surrounding AV/CV vehicles; and no new barriers or reporting requirements for technology integration related to AV/CV vehicles.
- Maintain NHTSA enforcement, defect, and recall authority for AV/CV vehicles and roadway technology when deploying.
- When deploying ADS roadway safety elements, focus on system safety; operational design domain; object and event detection and response; fall back (minimal risk condition); validation methods; human-machine interface; vehicle cybersecurity; crashworthiness; post-crash ADS behavior; data recording; consumer education and training; and federal, state, and local laws.

3 Alignment with the I-70 PEL Study Purpose and Need

Further use of ITS and implementing AV/CV technology on I-70 were identified as strategies that would support the identified needs of the I-70 PEL Study to improve safety, system performance, and freight movement. Technology improvements can be used to supplement, delay, or even eliminate the need for transportation infrastructure projects intended to address high crash locations, congestion, or freight bottlenecks.

3.1 Safety

As noted in the *I-70 Planning and Environmental Linkages (PEL) Study Conditions Assessment Report* (MoDOT 2017), safety for both motorized and non-motorized travel in the Study Corridor has been identified as an issue. All sections of I-70 in the Study Corridor have higher vehicular crash rates than the statewide average, and clusters of pedestrian and bicycle crashes have also been identified in specific areas.

Safety is a key motivation for ITS and AV/CV deployment. ITS increases motorist awareness of the travel environment, helping them to be aware of unsafe or poor travel conditions (i.e., inclement weather, incidents).

CVs expand on ITS benefits by distributing information more quickly over a wider area, which may include more remote areas that are difficult to reach with today's ITS. CV technology receives information about weather advisories, general traffic-related information, and safety-related advisories about the behavior of other vehicles. Vehicles in constant communication can be aware of each other—even if their sight-lines are obstructed—improving the likelihood that motorists will avoid incidents when they encounter hazards such as sudden braking, lane changes, and blind corners and intersections.

AVs expand on this even further by using technology to remove human error and allow a computer to make quick decisions. AVs have the potential to more appropriately respond to hazards and other situations in an effort to reduce injury or harm to the driver, other motorists, or bicyclists and pedestrians. Examples of autonomy include simple features like active lane control, steering, throttle (i.e., cruise control), or braking.

3.2 System Performance

ITS improves system performance by allowing MoDOT to manage traffic flows through mobility information exchanged in real-time. ITS applications enable MoDOT to monitor roadway conditions and deploy adaptive measures, such as delivering travel time information, implementing traffic signal timing changes, opening express lanes, and delivering weather advisories. These measures improve system performance through support of incident management and congestion monitoring.

In a CV environment, system performance is improved by allowing vehicle-to-vehicle (V2V) communications and vehicle-to-infrastructure (V2I) communications. These CV applications allow for real-time data exchange that communicates vehicle actions, enabling MoDOT to monitor and improve overall system performance. These applications also allow drivers to be aware of data from other vehicles so that drivers can perform potential countermeasures, such as alternate route selection.

AV technology further improves system performance by minimizing and/or removing human error and behaviors that cause congestion. Such impacts to system performance include excessive/unnecessary braking and slowdowns, as well as aggressive and unsafe driving. AVs can also operate safely with less buffer between vehicles, which increases the capacity of existing roadway infrastructure.

3.3 Freight Movement

The benefits of ITS, CV, and AV related to freight movement are similar to the benefits for overall system performance discussed above. Using ITS, freight operators can receive real-time updates that directly impact their carrier's ability to deliver, such as wait times near intermodal hubs or available parking spaces at designated rest stops. Although ITS can currently relay general travel information around the St. Louis region to freight operators entering the area at dedicated traveler information points (e.g., Dynamic Message Signs [DMS]), a CV-enabled system would allow these operators to receive constant data feeds at several additional points. AV technology benefits for truck operation would be similar to those for passenger vehicle operations, which would potentially reduce the impact that large commercial vehicles can have on traffic operations.

4 Existing ITS Technology on I-70

4.1 Current MoDOT ITS Program

On key transportation routes such as I-70, MoDOT uses ITS and ITS-enabling devices to help support incident management, congestion monitoring, and distribution of traveler information. This ITS programing is referred to as MoDOT's Gateway Guide program. The MoDOT Transportation Management Center (TMC) serves as the transportation information hub for the St. Louis region by operating and supporting the Gateway Guide.

MoDOT's TMC supports ITS-enabling field devices in the St. Louis region through use of a fiber optic communications network. Network hubs are located throughout the region, linked to each other and the TMC through a 72-strand fiber optic trunk cable, and to local devices via a 24-strand fiber optic distribution cable. I-70 serves as a critical travel link in the St. Louis region for sending data from the east to the west and provides redundancy for fiber cuts elsewhere in the system. Along I-70, CCTV cameras, DMS/VMS, and microwave vehicle detection systems (MVDSs) are deployed using the 24-strand distribution fiber optic cable to communicate with adjacent hub cabinets. The 72-strand trunk fiber optic cable communicates data from hub to hub and back to the MoDOT TMC.

MoDOT uses CCTV cameras to remotely monitor traffic conditions along I-70 and other key travel routes. MVDSs are located at select areas along the corridor. These MVDSs were previously owned by a third party (traffic.com), but were transferred to MoDOT ownership. MoDOT monitors road conditions using traffic data from a company called HERE, which tracks probe vehicles independently to determine traffic conditions. MoDOT also uses road weather information stations (RWIS) to collect localized pavement and weather conditions.

MoDOT communicates information to motorists on I-70 using DMS, also known as Variable Message Signs (VMS). DMS/VMS are permanent installations that provide variable information in real-time to passing motorists regarding roadway incidents, general safety, and travel times. MoDOT also uses Adaptive Control Software Lite (ACS-Lite) and an Adaptive Control Decision Support System (ACDSS) at select traffic signals in the Study Area to allow computer-controlled timing changes to be made in response to real-time traffic conditions.

4.2 Immediate Plans for MoDOT ITS Program

MoDOT's fiber network in the St. Louis region is fairly mature, but may not be able to accommodate the extra bandwidth required for CV-enabled transceivers. This can be addressed through improvements in network communication switches and other assets that can transmit and receive at higher bandwidths. MoDOT anticipates deploying CV-enabled radios when standards and practices are formally adopted at a national level. Similarly, MoDOT will look to federal guidelines for best practices in accommodating AVs. This is an economical strategy to deploy only those solutions that have been vetted and accepted nationally, instead of those that are experimental and may change in the future.

5 Current I-70 Readiness for AV/CV Technology

To help assess CV/AV preparedness and existing technology in the Study Corridor, the Colorado DOT has proposed a Connected Roadway Classification System (CRCS) that was used to assess the current infrastructure in the Study Corridor. This classification system, which is described in Appendix B, classifies how well a roadway facility is prepared for using CV/AV technology according to six levels, with Level 1 being the least prepared and Level 6 being fully prepared.

The Study Corridor was divided into two-mile segments for eastbound and westbound. Each segment was classified as its own entity. If any part of the two-mile road segment met the criteria under the classification levels noted above, it was assigned to that level. Using this assessment method, the entire Study Area was classified as a CRCS Level 3 roadway, with the exception of US 61 north of I-70 near mile marker 210 and Riverview Boulevard near Mile Marker 247, which were classified as CRCS Level 2 roadways. Considering the low presence of AVs compared to the number of driver-operated vehicles, a CRCS Level 2 to 3 ranking is appropriate for today's driving environment. As AVs become a larger proportion of the vehicle fleet, a transition to higher classification levels is needed for traffic operations to function more efficiently.

6 Recommendations

Recommendations for implementing ITS and CV/AV technologies within the Study Corridor are consistent with those in current planning studies summarized in this memorandum, and focus on measures to align with the I-70 PEL Study Purpose and Need. The recommendations refer to the SAE Levels of Autonomy, which are described in Appendix A.

6.1 Near-Term Recommendations

The near-term timeframe is defined as zero to four years from the writing of this document. Within this timeframe, CV standards are being studied across the country as part of pilot project efforts, but no standard or practice has been formally adopted. With the exception of prototypes, almost no AVs are present in the road environment.

6.1.1 Supplement ITS in strategic areas

Supplement MoDOT's existing ITS program along the Study Corridor by investing in ITS measures such as adding CCTV cameras to fill in gaps in coverage and adding DMS to provide greater traveler information. It is recommended that technology systems be strategically integrated with infrastructure improvements at key areas.

Over time, the speed and resiliency of network communications equipment is expected to advance. Ongoing investment in expanding data transmission capabilities will better allow CV-enabled data to be exchanged between MoDOT and road users in the future.

6.1.2 Invest in CV deployment prerequisites

Many CV standards and practices are still being developed at the national level. While several states have initiated pilot projects, these standards are not at a "road ready" level of completeness to be uniformly adopted, and currently there are only a few CV-enabled vehicles on the road to use the system. While investing in a "non-pilot" system may be a few years away, several incremental measures are recommended to better prepare for CV deployment:

- Adopt the FHWA *Vehicle to Infrastructure (V2I) Message Lexicon* (Federal Highway Administration [FHWA] 2016), which provides a series of ITS standards that define the connected vehicle (CV) interface to other vehicles, personal devices, and the infrastructure, as well as technical guidance for constructing and deconstructing (sending/receiving) data message packets. Some transportation agencies have begun developing add-on modules to their traffic management software that are able to process CV data, so that their system is ready to receive and process data as soon as CV-enabled equipment is deployed.
- Identify and develop plans for CV roadside unit mounting locations along I-70. The locations will require a reliable power supply and adequate line of sight on I-70 from antennas.
- Establish two secure backhaul communication links along I-70 at existing link locations, one for ITS/traffic signal data and the other for CV data.

- Make sure that ITS equipment or controllers comply with National Transportation Communications for ITS Protocol (NTCIP) standards.
- Make sure that roadside cabinets along I-70 have sufficient space to house an external processor (size depends on application).
- Consider using the existing express lanes in the City of St. Louis to test AV/CV.

6.2 Mid-Term Recommendations

The mid-term timeframe is defined as five to 14 years from the writing of this document. Within that timeframe, it is anticipated that CV standards will have been formalized at the national level and a “road ready” solution will be present in a minimum capacity. Some AVs may be present in the road environment, but they are anticipated to be SAE Level 3 vehicles (minimum driving requirements done by the AV) at best.

6.2.1 Update standards for signing, striping, and traffic control devices

The Transportation Research Board’s Task-Order Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies (TRB 2018) and Caltrans’ I-5 widened striping pilot program indicate that implementing AV signing and striping standards will serve both human drivers and SAE Level 3 to 5 vehicles more efficiently. Also, the latest edition of the Manual on Uniform Traffic Control Devices (MUTCD), currently under development with FHWA, will determine how traffic control devices and roadway signage and striping will function in an environment that includes AVs. It is recommended that current MoDOT standards be reviewed and updated to improve safety and traffic operations for the current system and to facilitate the transition to a more automated system; this may include use of more reflective pavement markings/striping and barrier reflectors as well as wider more visible lane markings/striping. Infrastructure can be brought up to the new standards via standalone projects or implemented in conjunction with other low-cost improvements, such as resurfacing or guardrail replacement.

6.2.2 Invest in CV-enabled roadside units in strategic areas

CV-enabled roadside units relay information between CVs and the TMC. CV-enabled vehicles will already be able to track and respond to other CV-enabled vehicles for collision avoidance and exchange of road condition information. CV-enabled roadside units will collect these transmissions and relay them to the TMC to help MoDOT understand the travel conditions along the road. Similarly, CV-enabled vehicles will be able to receive updates from the CV-enabled roadside units about travel conditions on the rest of the network such as curve speed warning alerts, stopped traffic ahead alerts, and road condition notices.

6.3 Long-Term Recommendations

The long-term timeframe is defined as 15 to 25 years from the writing of this document. By that time, it is anticipated that CV standards are being maintained, incremental improvements are being offered for hardware or software solutions, and CV-enabled vehicles account for nearly all of the vehicle fleet. Most vehicles will be functioning at an SAE Level 3 (minimum driving requirements automated) and vehicles functioning at SAE Levels 4 and 5 (most to all driving requirements automated) are becoming a larger portion of the vehicle fleet (20+ percent).

6.3.1 Implement AV-only lanes

In the long-term timeframe, a mixed AV/CV and non-AV/CV driving environment is expected, with a need to meld requirements/standards to safely and efficiently accommodate all vehicle types. Because AVs can operate safely with narrower travel lanes and no shoulders, the existing pavement width can be repurposed to incorporate AV lanes. Where existing shoulders are wide enough on the left side of the road, full-depth pavement can be installed for use by AVs. When mainline capacity expansions are considered, two AV lanes could be installed on the left side of the road in the same space as one general purpose lane with a shoulder. It is expected that FHWA and the National Highway Traffic Safety Administration (NHTSA) will have standards and guidance on this type of transition during this timeframe.

6.4 Future-Term Recommendations

The future-term timeframe is defined as a period that is 25 years beyond the writing of this document. In this timeframe, it is anticipated that SAE Level 5 (fully autonomous with no human intervention necessary) AVs are widely used, and SAE Level 3 and 4 vehicles are slowly being phased out. Nearly all vehicles are equipped with CV-enabled transceivers to improve operational efficiency of the AV.

6.4.1 Implement advanced roadway guideway systems (ARGS)

Advanced roadway guidance systems (ARGS) communicate detailed mapping of roadway geometry, lane designations, wayfinding, and roadway conditions in real-time to AVs/CVs. These systems, which are appropriate for SAE level 4 or higher, can be implemented for specific lanes or for the entire roadway. When the road environment has transitioned to full automation, no roadside signs are needed on the roadway or lanes, as all roadway information is transmitted directly to vehicles on-board systems from V2I assets.

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8 Abbreviations and Acronyms

Acronym or Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
ACDSS	Adaptive Control Decision Support System
ADS	Automated Driving System
ARGS	Advanced Roadway Guideway System
AV	Automated Vehicle
CCTV	Closed-Circuit Television
CRCS	Connected Roadway Classification System
CV	Connected Vehicle
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
EWG	East West Gateway Council of Governments
FHWA	Federal Highway Administration
ITS	Intelligent Transportation System
LOS	Level of Service
MoDOT	Missouri Department of Transportation
MOT	Maintenance of Traffic
MUTCD	Manual on Uniform Traffic Control Devices
MVDS	Microwave Vehicle Detection System
NHTSA	National Highway Traffic Safety Administration
NTCIP	National Transportation Communications for ITS Protocol
PEL	Planning and Environmental Linkages

RWIS	Road Weather Information Stations
SAE	Society of Automotive Engineers
TMC	Transportation Management Center
TRB	Transportation Research Board
U.S. or US	United States
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VMS	Variable Message Signs

Appendix A: Society of Automotive Engineers Levels of Autonomy

Automated driving occurs at varying degrees, based on the levels that the AV systems are in control and the requirements needed for minimum human driver intervention. To formulate a common template, the Society of Automotive Engineers (SAE) International published their J3016 standard, titled *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. This standard identifies six levels of driving automation that range from no automation to full automation. Although not stated to imply a particular order of market introduction, it is widely viewed that the levels are progressive.

The SAE International J3016 Levels of Automation are defined below. Level 0 describes the majority of vehicles on the road today. Level 3 describes the minimum requirements for a truly automated vehicle, where the dynamic driving task is fully controlled by the vehicle (with an expectation that the human driver will respond when the vehicle notes a need to intervene). Level 5 describes a vehicle that is fully autonomous and has no human invention required.

SAE Levels of Autonomy Definitions

Level	Definition
Level 0 (No Automation)	All aspects of driving are done manually by a human driver.
Level 1 (Driver Assistance)	All aspects of driving are done manually by a human driver. Some driver assistance features provide basic autonomous response, such as either automatic braking or lane control assist (but not a capability to do both).
Level 2 (Partial Automation)	All aspects of driving are done manually by a human driver. Some driver assistance features provide basic autonomous response, such as both steering and acceleration/deceleration capabilities. Some examples include "stay in lane" automatic corrections and self-parking features.
Level 3 (Conditional Automation)	Minimum driving requirements are done by the autonomous vehicle using sensors to detect the environment around them. Human override is required when the machine determines that it is unable to execute the task at hand.
Level 4 (High Automation)	Most driving requirements are done by the autonomous vehicle using sensors to detect the environment around them. These vehicles can operate with very minimal need for human attention, although intervention may be necessary for particular niche cases, such as off-road driving environments.
Level 5 (Full Automation)	All driving requirements are done by the autonomous vehicle using sensors to detect the environment around them. These vehicles have no need for human attention and may operate without a human driver present. These vehicles would have an advanced environmental detection system and could operate in complex or atypical road environments.

Appendix B: Colorado Connected Road Classification System (CRCS)

Colorado's proposed Connected Roadway Classification System (CRCS) classifies the operational environment of a road relative to deployment of CV/AV and the distribution of AV/non-AV drivers; this is a DRAFT classification system awaiting National Cooperative Highway Research Program (NCHRP) evaluation. It is under consideration by MoDOT to provide a number of important lessons and key opportunities for knowledge transfer and application. With Level 1 representing a road that is the least-prepared, Colorado's CRCS levels are defined below:

CRCS Classification Level Definitions

Level	Definition
Level 1 Roadway	Unpaved and/or non-striped roads designed to a minimum level of standard of safety and mobility.
Level 2 Roadway	Paved roads designed to the American Association of State Highway and Transportation Officials' (AASHTO's) standards with MUTCD fixed signage and pavement markings. There is no ITS equipment or communications infrastructure to support connected vehicle data. Access to cellular data service may be available.
Level 3 Roadway	There is ITS equipment operated by a Traffic Operation Center (TOC), with communications infrastructure between ITS equipment and the TOC. Communications network has sufficient bandwidth to support one-way electronic data sharing between DOT/vehicle/user and/or mixed-use lanes. Existing ITS infrastructure can readily support vehicle to infrastructure (V2I) communications with supplemental equipment (e.g., Dedicated Short-Range Communications [DSRC] radios) added to the existing architecture.
Level 4 Roadway	Roadway or specific lane(s) has adaptive ITS equipment (i.e., smart signals hold for vehicles, highway lighting that turns on for vehicles, etc.) with TOC monitoring and override capabilities. Communications between TOC and ITS has sufficient bandwidth for one and/or two-way data share between DOT/vehicle/user, and/or lanes designated for SAE Level 3 and 4 (i.e., "Conditional Automation" and "High Automation" vehicle levels) only. Existing ITS infrastructure can readily support vehicle to infrastructure (V2I) communications with additional equipment (e.g., DSRC).
Level 5 Roadway	Advanced guideway system roadway or specific lane(s) designed for SAE Level 4 (i.e., "High Automation") only with additional features that may include inductive charging, advance/enhanced data sharing, etc. Existing infrastructure in place to support V2I communications. Additionally, no roadside signs are needed on the roadway or lanes, as all roadway information is transmitted directly to vehicles on-board systems from V2I assets.
Level 6 Roadway	All lanes on a roadway designed for SAE Level 4 (i.e., "High Automation") systems - no signs, signals, or striping needed.

Other Recommended Segment-Level Strategies

The prioritization process presented in Chapter 4.0 of this I-70 Planning and Environmental Linkages (PEL) Study report resulted in a second-tier of strategies for each segment that would do a reasonably good job of addressing the goals in each segment, but would either offer less benefit than the high-priority strategies or would have considerably higher potential for impacts. While they are not discussed in Chapters 5.0 and 6.0 of this PEL Report, they are recommended for further consideration. These additional recommended strategies in each segment are listed below along with a general discussion of how each might be applied. A few strategies in particular were included in this category even though benefits were not rated as high as other recommended strategies. Low-cost transit enhancements have been recommended in all segments because they would benefit underserved communities and are an integral component to achieving the Purpose and Need of this Study, which includes improving multi-modal mobility. Transportation System Management (TSM) is another strategy recommended in all segments as a low-cost, low-impact measure to improve traffic operations. Addressing weave sections was also recommended in all segments because it was considered an essential component of addressing safety issues in the Study Corridor.

Other Recommended Strategies in Segment 1

- **Address weave sections.** Weave issues at the I-64 interchange could be addressed as part of the interchange reconfiguration recommended in the high-priority strategies for this segment.
- **Add mainline capacity.** With much of the segment projected to operate at Level of Service (LOS) F in the AM and PM peak hours by 2045, additional mainline capacity may be needed as far west as Wentzville, which is one of the fastest growing communities in St. Charles County. Adding mainline capacity could be considered as needed to supplement interchange and parallel route improvements, both of which are high-priority strategies expected to improve LOS on the mainline.
- **Bring the facility to current standards[1].** Four bridges in Segment 1 currently have vertical clearance less than 16 feet 6 inches, which is the current standard. At US 61 S and I-64 W, vertical clearance could be brought to current standards as part of the proposed I-64 interchange reconfiguration identified in Chapter 5.0. Vertical clearance at Lake St. Louis Boulevard E and S. Woodlawn Avenue could be brought to current standards when replacement of the bridges is warranted. More information on these bridges is available in Appendix A, Table 2-6.
- **Implement TSM measures.** In combination with some of the interchange improvements identified in Chapter 5.0, TSM measures such as ramp metering and signing/striping improvements would help maximize infrastructure efficiency. Metering would be beneficial at Guthrie Road, Bryan Road, and Route K on-ramps.
- **Low-cost transit enhancements.** With limited public transit options currently in place, expansion of the local transit system is needed to improve access to public transit in Segment 1. As documented in the *I-70 PEL Conditions Assessment Report*, a considerable number of people living in Segment 1

[1] While future projects will seek to bring infrastructure to standards, this may not always be practicable. Design variances will be considered during project development on a case by case basis.

commute to employment centers along I-70 in the western portion of St. Louis County, and to a lesser extent, in the City of St. Louis. Efficient transit access to the North Hanley Transit Center would be beneficial.

Other Recommended Strategies in Segment 2

- **Address weave sections.** Merging traffic at interchanges results in traffic weaving in this segment that impacts LOS. The interchange improvements and auxiliary lane identified in Chapter 5.0 would partially address this issue. Additional auxiliary lanes in this segment would be beneficial in further addressing weave sections that impact I-70 LOS.
- **Add mainline capacity.** Portions of this segment are projected to operate at LOS F in the AM and PM peak hours by 2045. Additional mainline capacity could be considered if needed to supplement interchange and parallel route improvements, both of which are high-priority strategies expected to improve LOS on the mainline.
- **Bring the facility to current standards[2].** Three bridges in Segment 2 currently have vertical clearance less than 16 feet 6 inches, which is the current standard. At Hwy. 79/Salt Lick Road and Cave Springs Road, vertical clearance could be brought to current standards as part of the proposed interchange reconfigurations identified in Chapter 5.0. Vertical clearance at Executive Center Parkway could be brought to current standards when replacement of the bridge is warranted. More information on these bridges is available in Appendix A, Table 2-6.
- **Implement TSM measures.** In combination with some of the interchange improvements identified in in Chapter 5.0, TSM measures, such as ramp metering and signing/striping improvements, would help to maximize infrastructure efficiency. For example, metering would help maximize the efficiency of vehicles entering the interstate at Cave Springs Road, where both AM and PM LOS are projected to range from D to F in 2045.
- **Low cost transit enhancements.** As documented in the *I-70 PEL Conditions Assessment Report*, a considerable number of people living in Segment 2 commute to employment centers along I-70 in the western portion of St. Louis County, and to a lesser extent, in the City of St. Louis. To build on the I-70 commuter route currently operated by St. Charles Area Transit (SCAT), strategies for low cost transit enhancements include increased frequency of service, improved travel times, and first and last mile[3] options.

Other Recommended Strategies in Segment 3

- **Address weave sections.** Weave issues at the Hwy. 141 and I-270 interchanges could be addressed as part of interchange reconfigurations recommended in the high-priority strategies for this segment.
- **Add mainline capacity.** Portions of the segment are projected to operate at LOS F in the AM and PM peak hours by 2045. Additional mainline capacity could be considered if needed to supplement

[2] While future projects will seek to bring infrastructure to standards, this may not always be practicable. Design variances will be considered during project development on a case by case basis.
[3] First and last mile refers to providing transit connections between a person's start point (e.g. their home) to a transit stop/station and from a transit station/stop to their final destination (e.g. their job).

interchange and parallel route improvements, both of which are high-priority strategies expected to improve LOS on the mainline.

- **Implement TSM Measures.** TSM measures such as ramp metering and signal timing optimization would help to maximize infrastructure efficiency. If Hwy 141/Earth City Expressway is reconfigured, ramp metering would be beneficial at that location. Ramp metering and signal timing optimization would also be beneficial at Hwy 94 and 5th Street.
- **Low cost transit enhancements.** Metro strategies in this segment include increased frequency bus connections between Earth City and North Hanley Transit Center and shuttles/on-demand transit service in Earth City.

Other Recommended Strategies in Segment 4

- **Address weave sections.** Weave issues at Hwy. 67 and I-170 could be addressed as part of interchange reconfigurations recommended in the high-priority strategies for this segment. Weave issues at Natural Bridge Road could be addressed by interchange reconfigurations and/or ramp improvements at that location.
- **Improve operations of interchanges.** The interchange improvements recommended in the high-priority strategies for this segment would substantially improve interchange operations. Another strategy recommended in this segment is auxiliary lanes, which would reduce congestion on interchange ramps. Target areas would include the I-70 section between Cypress Road and Natural Bridge Road and I-170 and Hanley Road.
- **Improve freight access to the airport.** As interchanges accessing the airport are reconfigured, design criteria should accommodate large commercial vehicles and oversized loads.
- **Improve wayfinding at the airport.** Strategies include improved signage at interchanges to direct patrons to their desired destinations at the airport.
- **Add mainline capacity.** Portions of the segment are projected to operate at LOS F in the AM and PM peak hours by 2045. Additional mainline capacity could be considered if needed to supplement interchange improvements and curve corrections, both of which are high-priority strategies expected to improve LOS on the mainline.
- **Implement TSM measures.** Strategies include signal timing optimization, ramp metering, or signing/striping improvements. Signal timing optimization at Cypress Road, Air Flight Drive, and N Hanley Road would improve traffic operations as would ramp metering at St. Charles Rock Road, Cypress Road, Air Flight Drive, and Natural Bridge Road. Signing and striping improvements would also be beneficial on Natural Bridge Road.
- **Low cost transit enhancements.** Metro strategies include increased MetroBus frequency between North Hanley Transit Center and the Civic Center Station. The Missouri Department of Transportation (MoDOT) strategies in Segment 4 include transit signal priority for buses and project designs promoting safe and efficient bicycle and pedestrian access to transit stops on MoDOT routes in the Study Area.

Other Recommended Strategies in Segment 5

- **Upgrade infrastructure to better accommodate freight (including implementation of MoDOT and Freightway priority projects).** While the strategy to better accommodate freight did not rank as highly as other strategies in Segment 5, many of the high-priority strategies in the segment would serve this purpose. Addressing safety and congestion along I-70 through interchange improvements and curve straightening would reduce impediments to freight movement. Raising bridge heights to current standards as part of interchange and bridge improvements would better accommodate large commercial vehicles.
- **Improve safety and function of collector/distributor roads.** In Segment 5, routes such as Bircher Boulevard and 11th Street function as both a collector/distributor system for the interstate and as residential collector streets. Recommendations for improvements to such routes include traffic calming measures and intersection improvements to safely distribute traffic to nearby residential areas.
- **Address weave sections.** Inadequate length of entrance/exit ramps at interchanges results in traffic weaving in this segment. The interchange improvements and auxiliary lane identified in Chapter 5.0 would partially address this issue. Additional auxiliary lanes in this segment would be beneficial in addressing weave sections.
- **Implement TSM measures.** Strategies would include signal timing optimization and improved incident response.
- **Low Cost Transit enhancements.** Metro strategies include express bus service between downtown and the North County Transit Center, more local bus routes and increased frequency, and shuttles/on-demand service downtown. Commuter bus service connecting the workforce in the City of St. Louis with suburban employment centers is also recommended. Because this involves service beyond Metro's service area, this strategy would require the cooperation of local jurisdictions for funding and operation. MoDOT strategies in Segment 5 include transit signal priority for buses and project designs promoting safe and efficient bicycle and pedestrian access to transit stops on MoDOT routes in the Study Area.
- **Moderate cost transit enhancements.** Metro completed a bus rapid transit (BRT) study that recommended two routes. There is no current plan to move this study forward until a decision is made on the Northside/Southside LRT Extension because there is an overlap in the routes.