CONNECTED VEHICLE TECHNOLOGY

A Primer for the I-70 Coalition and Stakeholders

Kevin Pula
kevin.pula@cudenver.edu
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Executive Summary

The purpose of this Primer is to summarize the current connected vehicle technology (CVT) pilot projects taking place across the country for the benefit of the I-70 Coalition as it considers the CVT applications being introduced within the I-70 Mountain Corridor.

A review of the literature identifies the theoretical and demonstrated applications of CVT within a variety of transportation environments. A range of communication paradigms and technologies are explored. Various transportation issues, namely safety and congestion issues, are explored in the context of the ability of CVT to provide a solution. Further, second-order benefits and externalities to the deployment of CVT are discussed.

Eight CVT pilots are analyzed using primary source data and practitioner interviews when applicable. Three research questions are considered: What is connected vehicle technology (CVT), in what applications can it improve safety and congestion outcomes, and what adoption hurdles currently exist?; How are jurisdictions currently using or testing connected vehicle technology as a transportation demand management tool?; What options are viable tools in the I-70 Mountain Corridor and can contribute to the Coalition's transportation demand management (TDM) goals?

A qualitative analysis through research observation was conducted to analyze the eight pilot projects currently underway in North America. The research findings indicate that Colorado is advanced in its progress towards testing and implementing CVT and other pilots are limited in their ability to inform local stakeholders due to the nascent nature of the technology.

The Coalition's goal of advancing TDM strategies is likely to be enhanced using third-party CVT applications which could focus beyond the on-road intervention of driving and encourage the reconsideration of how driver's use the I-70 Corridor.

Table of Contents

List of Tables

List of Acronyms and Abbreviations

AADT – Average Annual Daily Traffic
AASHTO – the American Association of State Highway Transportation Officials
AERIS – Applications for the Environment: Real-Time Information Systems
AV – Autonomous Vehicle
Caltrans – The California Department of Transportation
CDOT – the Colorado Department of Transportation
Coalition – The I-70 Coalition
Corridor – Colorado's I-70 Mountain Corridor
CV – Connected Vehicle
CVT – Connected Vehicle Technology
DSRC – Dedicated Short-Range Communications
EEBL – Emergency Electronic Brake Light
FAC – Freight Advisory Committee
FHWA – the Federal Highway Administration
IMA – Intersection Movement Assist
ITS/JPO – the USDOT's Intelligent Transportation System Joint Program Office
LTA – Left Turn Assist
MMITSS – Multi-Modal Intelligent Traffic Signal Systems
MTA – the Metropolitan Transportation Authority
NCHRP – the National Cooperative Highway Research Program
NHTSA – the National Highway Transportation Safety Administration
NOCoE – the National Operations Center of Excellence
NYCDOT – the New York City Department of Transportation
OBU – On-board Unit
Primer – The Connected Vehicle Technology Primer
RFID – Radio-Frequency Identification
RSU – Road-side Unit
SPaT – Signal Phasing and Timing
TDM – Transportation Demand Management
THEA – Tampa-Hillsborough Expressway Authority
UPS – United Parcel Service
UDOT – the Utah Department of Transportation
USDOT – the United States Department of Transportation
VCC – Virginia Connected Corridors
VDOT – the Virginia Department of Transportation
VTTI – Virginia Tech Transportation Institute
V2I – Vehicle-to-Infrastructure Communication
V2V – Vehicle-to-Vehicle Communication
V2X – Vehicle-to-Everything/Anything Communication
WYDOT – the Wyoming Department of Transportation

Introduction

This Connected Vehicle Technology Primer (the Primer) explores the following questions:

1. What is connected vehicle technology (CVT), in what applications can it improve safety and congestion outcomes, and what adoption hurdles currently exist?
2. How are jurisdictions currently using or testing connected vehicle technology as a transportation demand management tool?
3. What options are viable tools within the I-70 Mountain Corridor and can contribute to the Coalition's transportation demand management (TDM) goals?

The goal of the Primer is to present strategies and case studies for the I-70 Coalition (the Coalition) and its member communities to reflect upon when considering and encouraging the adoption of CVT. CVT is a promising, but nascent, technology-based solution to solving pressing transportation challenges, including those facing Colorado's I-70 Mountain Corridor (the Corridor) and thus the Coalition.

Background

The Coalition is a non-profit organization made up of 28 local governments and businesses along the Corridor. The Coalition's mission statement—"to enhance public accessibility and mobility in the I-70 Central Mountain Corridor and adjoining dependent counties and municipalities through the implementation of joint public and private transportation management efforts"—centers around long-standing transportation concerns in Colorado's mountain communities (I-70 Coalition, 2018).

The Corridor—roughly spanning from central Jefferson County to Eagle County—is an important freight connection between Colorado's Front Range, Western Colorado and the Western United States, as well as a vital commuting network for thousands of Coloradans. Further, the corridor is unique in that it faces extreme levels of recreation-based traffic from millions of Coloradans and out-of-state visitors alike.

A 2014 traffic and revenue study from the Colorado Department of Transportation (CDOT) estimated, under a “no build” scenario, annual corridor vehicle trips will be 25.7 million in 2025 growing to 43.4 million in 2075. The total estimated growth rate for the 50-year timeline is 68 percent with annual growth rates ranging from 8 to 14 percent (Louis, 2014). Congestion events are regularly experienced in the corridor which negatively impacts motorist’s mobility and safety, the economy, and the environment.

Many private stakeholders and public agencies, including CDOT and the Coalition, are seeking long-term mobility solutions for the corridor. Expanded capacity (CDOT, 2011), public transportation (CDOT, 2014), safety improvements and environmental solutions are all part of the collective vision for the future of the corridor.

The primary short-term goal of the Coalition is the implementation of non-infrastructure improvements and TDM strategies. Specifically, as stated in the coalition’s TDM Work Plan (2015, pp. 1-2), these strategies include traveler education and outreach; partnerships with businesses and industry; promotion of TDM strategies through resorts, local governments, and tourism-based organizations; support of carpooling and carpool parking; and supporting and promoting transit.

CVT may play a vital role in these five areas of focus, providing local communities with an additional tool to achieve their stated short-term goals. However, as these emerging technologies quickly develop into viable tools for transportation planning, design, and operation, governments will need to consider their potential benefits, costs, and shortfalls.

Literature Review: CVT Primer

Definition of a Connected Vehicle

Connected vehicles (CV) and connected vehicle technology are terms used for a wide variety of technologies being explored in the transportation space. Depending on the audience, opinions about the utility and ultimate deployment of CVT exists on a spectrum between public good and a private-sector paid service. Is CVT a tool for governments to better deliver public goods? Is CVT a tool to leverage motorists' insatiable need for connectivity? Should CVT be an eventual safety mandate by the government? Will it be a tool to provide benefits to all or only to those with the means to access it? The answer is likely to be some combination of all the above. Government will need the private-sector to advance the technologies and industry will likely lean on government to guide and require some aspects of deployment.

According to the United States Department of Transportation's (USDOT) Intelligent Transportation Systems Joint Program Office (ITS/JPO), the connected vehicle environment is predicated on robust wireless connectivity among vehicles, roadway infrastructure and mobile communication devices. Through effective communication between these three classes, "transformative changes" can be realized in the transportation arenas of safety, mobility and environmental externalities (Hill & Krueger, 2018).

Others consider the benefits of CVT in terms of the user experience and consumer benefits beyond the transportation network implications. IBM views CVT as a marketplace of sorts where companies can access their customers, classifying connected vehicles as any "vehicle capable of seamless integration with multiple systems, connecting consumers with their digital world….develop[ing] an interdependent ecosystem of suppliers and partners to help them deliver innovative services to their customers (as cited in Brookes & Pagani, 2014, sec. 4).

Blending these two paradigms, Coppola and Morosio (2016, pp. 46:3-46:4) define a CV to be a vehicle capable of four major functions: accessing the internet ubiquitously, providing "advanced infotainment features" to the drivers or passengers through applications or devices, integrating with infrastructure and other smart devices, and integrating with other vehicles.

According to CDOT (2017), a connected vehicle is:

> "A vehicle that can send and receive information from other vehicles, CDOT systems and road infrastructure (e.g., traffic signals, roadway sensors) using multiple forms of communication… sends and receives important information about road conditions, delays and accidents by automatically communicating information such as the vehicle's speed, direction and brake status (Q. What is a "connected vehicle"?)."

CDOT's Smart 70 Project appears to centralize around the view of CVT as a tool to enhance an existing public good. Stated goals of the Smart 70 Project coalesce around the idea of enhancing motorists' safety, mobility and trip reliability via real-time informatics (CDOT, 2018a). However, the potential incentives and benefits of the private-sector are not ignored. Panasonic, CDOT's private-sector partner, seeks to develop a marketable product for which they can sell to other jurisdictions as a business endeavor. CDOT acknowledges the potential for consumer applications to leverage the Smart 70 CV Ecosystem (Kozinski, 2018), more closely reflecting the definition of CVT presented by IBM above. (See the Methodology and Analysis sections of the Primer, as well as Appendix A, for additional details on the Smart 70 Project.)

This Primer focuses on the public good and mobility improvements definition of CVT. Although, it is important to consider how the consumer and private-sector possibilities of the technology may help stimulate deployment and adoption.

Underlying Technology

CVT can be subdivided into categories based on type of communication tools used or the parties involved in the vehicle communication, primarily, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity.

The National Highway Transportation Safety Administration (NHTSA) defines V2V communication as "as crash avoidance technology which relies on communication of information between nearby vehicles to potentially warn drivers about dangerous situations that could lead to a crash (2017b)." Some of the discrete uses of V2V identified by NHTSA are intersection movement assist (IMA), left turn assist (LTA) and emergency electronic brake light (EEBL). The most relevant of these to an Interstate environment is EEBL which allows vehicles to be warned of significant issues out of the driver's line-of-sight either due to distance or poor weather conditions. V2V can also be used to supplement other vehicle systems to implement systems such as blind spot warnings and forward collision warning, both of which can help avoid common crashes in a highway environment.

Like V2V, V2I communication can inform a driver's decision making, potentially mitigating a potential safety or congestion episode. V2I provides drivers with information related to the driving environment (as opposed to the other vehicles on the road) such as weather, construction zones, lane restrictions or speed limit changes. V2I's impact on motorists differs from V2V in that it can impact strategic or future decisions rather than momentary operational actions (Talebpour & Mahmassani, 2016).

All types of CVT rely on wireless communications which can take several forms including dedicated short-range communications (DSRC), Wi-Fi, cellular protocols such as 5-G, radio-frequency identification (RFID) and others. Further, technologies outside of mainstream consumers' lexicons are being tested for "V2X" (vehicle to any other party), such as ZigBee (a communication technology operating on radio frequency), Ultra-Wideband radio technology and 60 GHz Millimeter Wave communication (Lu , Cheng, Zhang, Shen & Mark, 2014).

Major challenges of the implementation of one or multiple types of vehicle communication centralize around cost and complexity issues. The dynamic and “harsh” environment inside a vehicle creates a technology and cost hurdle to enabling consistent and effective service levels of co-operating communication technologies. Relying on CVT applications to inform driver or vehicle decision requires reliable and accurate information, dropping a signal or intermediate connectivity may strand a driver once a reliance on CVT applications becomes habit. Driver-side operational issues arise as well with the addition of competing information resources to the driver, requiring a novel solution for balancing a motorist’s attention of the roadway and the consumption of outside data or information (Lu , Cheng, Zhang, Shen & Mark, 2014).

Although CVs are often conflated with autonomous vehicles (AVs), these technologies are not reliant on each other to be implemented or used. A CV need not be autonomous and vice versa, however these technologies will likely be mutually beneficial to each other.

Potential Adoption Patterns

Adoption rates of CVs and AVs will be reliant on consumer preferences and cost of technology. Modeling of adoption rates is difficult due limited transference of previous automotive adoption trends (Bansal & Kockelman, 2017). America has a storied history with the personal automobile and the historical preferences related to driving are likely incongruent with future driving technologies. A paradigm shift of sorts is a likely prerequisite for widescale adoption of certain CVT and autonomous features. Motorist may be hesitant to fully trust travel time, weather, closure, and safety warnings provided through CVT applications, especially if these features are introduced alongside low-level autonomous technologies such as lane assistance, automatic breaking and automatic steering.

A first step might be for drivers to embrace increased levels of real-time information and then incorporate that data into vehicle-lead decision making and autonomous features. In a survey of more than 2,500 motorists, researchers found that 75.7 percent of Americans enjoy driving and 79.3 percent typically were not early adopters of technology. Further, 58.4 percent were afraid of AVs while alternatively, 50.4 percent and 42.9 percent of people were comfortable with V2V and V2I respectively. Overall, the survey found that less advanced features are likely to be nearly ubiquitous by 2045 while advanced automated driving technologies face a bigger adoption hurdle (Bansal & Kockelman, 2017). Due to its focus on "connected autonomous vehicles", the results of this survey are limited, but interesting nonetheless in the context of just connected vehicles. It was unclear to what degree respondents conflated AVs and CVT in this survey.

A recent survey by Viereckl et al. (2015) reported on car owners' preferences for connected vehicle based services. Motorists expressed a greater preference, in terms of willingness to pay, for consumable information related to their current or future trips than compared to information about their vehicle such as performance statistics (as cited in Coppola & Morisio, 2016).

According to the online statistics aggregator, Statista (2018), 98 percent of all cars sold worldwide in 2020 will be connected to the internet, up from 35 percent in 2015 and growing to 100 percent by 2025. Domestically, NHTSA, which has jurisdiction over motor vehicle safety standards, has issued a notice of proposed rulemaking calling for the requiring of all new light-duty vehicles to be capable of V2V communications via DSRC technology by 2023 (2017a).

What Can CVT Do?

The two primary categories of CVT applications involve safety and mobility (congestion) enhancements. Through various paradigms of communication (V2V, V2I or others) CVT can be used to enhance a driver's ability to make safe and prudent roadway decisions, or by directly having the vehicle intervene in the driving experience through features such as break assistance or lane awareness. The Federal Highway Administration (FHWA) provides an explanation of these applications (as cited in National Operations Center of Excellence [NOCoE], 2018a*)* as:

> "[CV] safety applications are designed to increase situational awareness and reduce or eliminate crashes through [V2V] and [V2I] data transmission that supports: driver advisories, driver warnings, and vehicle and/or infrastructure controls. [CV] mobility applications provide a connected, data-rich travel environment. The network captures real-time data from equipment located on-board vehicles (automobiles, trucks, and buses) and within the infrastructure (para. *Connected Vehicles).*"

Safety improvements.

Arguably the most impactful CVT benefit to society resides within the traffic safety domain. Traffic safety benefits can be realized through intervention of human behavior (fatigue, distraction, etc.) or through equipment manipulation (crash avoidance, driving assistance). Both approaches show promise and are likely to be most effective in some combination. The former is a real and significant danger, according to NHTSA (2017a), 3,450 traffic deaths were caused by drowsy or distracted drivers in 2016.

In a recent study from Australia which examined simulations of real-world crashes, focusing on common injury and fatal crash scenarios, researchers found that CVT could prevent between 37 and 86 percent of crashes with the highest avoidance rating coming with a combination of autonomous and connected technologies. Although, the results demonstrated that some crash scenarios are difficult for CVT to prevent, including low-angle deviations and approaches from the rear (Doecke, Grant & Anderson, 2015). Due to the absence of intersection based conflicts, these findings may infer that some common scenarios encountered within the I-70 Corridor are less than ideal candidates for a CVT solution.

Improvements to the traditional method of ramp metering have also been explored, both through a centralized (management by engineers) or decentralized (vehicles determining the best course of action) system. Antoniotti et al. (as cited in Rios-Torres & Malikopoulus, 2017) proposed a decentralized hybrid approach in which vehicles were actively informed by roadway sensors to determine when on-ramp merging should take place. This approach does not require V2V communication. Rios-Torres & Malikopoulus further reference other approaches which rely more heavily on V2V communication to optimize on-ramp coordination through speed adjustments, platooning and cooperative merging. The authors acknowledge further large-scale testing is needed and a critical question of how to integrate driver-operated connected vehicles and driver feedback into more autonomously controlled metering systems remains.

NHTSA (2017b) estimates, with a fully enabled DRSC fleet, that IMA and LTA applications will prevent up to 600,000 crashes, 270,000 injuries and save 1,080 lives each year. Combined with other V2V and V2I applications, nearly 80 percent of non-alcohol-related crashes could potentially be avoided.

Congestion and mobility improvements.

The second broad category of potential benefits arising from CVT centers around mobility improvements and congestion mitigation. Aside from safety improvements and fewer incident-related backups, CVT can mitigate one of the primary causes of congestion—driver response to disturbances—by allowing for less distance between vehicles and faster reaction time (Rios-Torres & Malikopoulus, 2017).

Researchers have begun to model roadway environments under various levels of technology penetration, attempting quantify the expected improvements on traffic flow. Market penetration of CVT will have a strong impact on the effectiveness of improving vehicle throughput. Notable improvements are observed as fleet adoption of CVT grows from 0 to 50%, however, to observe no negative or minimal flow rate impacts on a roadway, adoption rates will likely need to approach 90 percent. Further automation will complement CVT and the best simulated results of throughput are achieved with a combination of both technologies (Talebpour & Mahmassani, 2016).

Second-Order Considerations

In addition to safety and mobility, CVT has the potential to provide second order benefits such as vehicle emissions reductions (Zmud, Goodin, Kalra, & Thorn, 2017), fuel consumption (Rios-Torres & Malikopoulus, 2017), or motorist and passenger comfort (Talebpour & Mahmassani, 2016). As discussed earlier, these auxiliary benefits are not explored in depth in this Primer but nonetheless will be important to public interest and may contribute to an expedited deployment of CVT.

Estimated costs.

Schrank et. al (2015) estimate congestion causes seven billion hours of delay for U.S. motorists and carries a total annual cost of $960 per commuter and a total of $160 billion nationally (as cited in Zmud, Goodin, Kalra, & Thorn, 2017). NHTSA (2017a) estimates the cost to consumers for V2V system to be around $350 per new vehicle in 2020, eventually decreasing to the low $200s by 2058. Nationally the potential annual costs peak in the mid-2020s at as much s $6.4 billion. However total costs will decrease as well to $1.1 billion each year.

Environmental Applications.

The FHWA describes the potential environmental applications of CVT as (as cited in NOCoE, 2018a)*:*

> "[CV] environmental applications both generate and capture environmentally relevant real-time transportation data and use this data to create actionable information to support and facilitate 'green' transportation choices. They also assist system users and operators with 'green' transportation alternatives or options, thus reducing the environmental impacts of each trip. On-board equipment may also advise vehicle owners on how to optimize the vehicle's operation and maintenance for maximum fuel efficiency. The AERIS (Applications for the Environment: Real-Time Information Systems) program was initiated to investigate whether it is possible and feasible to generate/capture environmentally-relevant real-time transportation data from vehicles and the system, and then how this data may be used (para. *Connected Vehicles).*"

Land use and development.

Full realization of the benefits of CVT may lead to new circumstances that will impact transportation networks and planning. In a report from the National Cooperative Highway Research Program (NCHRP), a clearinghouse of objective academic and industry transportation related research to serve the needs of public agencies, researchers argue that improved safety, mobility and comfort arising from CVT (and eventually AVs) will have impacts on land development. In some models, impacts may include greater sprawl due to lower opportunity costs of travel. Conversely, if incorporated into transit services, demand for individual passenger vehicles may decrease, thus lowering the demand for capacity. Further, due to lower capacity demand arising from decreased parking or vehicle spacing needs (i.e. more vehicles can be operated in the same amount of space), the technology may free up (or not require additional) valuable land currently allocated to transportation (Zmud, Goodin, Kalra, & Thorn, 2017).

Aligning interests to diminish negative externalities.

Without proper alignment of public and private interests (i.e. profit motivation as discussed in the definitions section versus elimination of societal-level negative externalities), CVT may not reach its full potential for improving safety and mobility outcomes (Zmud, Goodin, Kalra, & Thorn, 2017).

While many current societal costs may disappear (i.e. fewer crashes or congestion) some costs will persist but the cost liability may shift parties. It is unclear where liability will fall if third parties or private-sector concessionaires have a significant role in the operations or decision making of personal automobiles. When crashes or other negative externalities do occur, if the private-sector distributors of CVT are faced with liability, the deployment models could be stagnated (Zmud, Goodin, Kalra, & Thorn, 2017). Yet, federal mandates of CVT may force its deployment with unclear determinations of liability allocation.

Cyber-security.

As advanced technologies become more pervasive in our everyday lives, cyber-security becomes a primary concern of manufacturers, governments, and users. Cyber-security issues are already of concern in the transportation space and will likely continue to grow as CVT and other transportation technologies are deployed. NHTSA (2017b) is addressing security issues of CVT proactively, working with industry partners to develop protocols for cyber-security of connected vehicles. Together these stakeholders are constructing unique systems for V2V communication building off existing protocols and encryption techniques. While outside of the immediate scope of this Primer, and thus not discussed further within, cyber-security will certainly be a factor in any deployment decision of CVT technologies and adoption patterns by motorists.

Literature Review Summary

CVT is broad term encompassing a variety of technologies and applications. Depending on the environment, goals, existing infrastructure and other conditions, individual jurisdictions may choose one method of communication or technology for their CVT applications. Depending on the desired outcomes, applications may include decision making at the network level by transportation engineers or, conversely, drivers may be more directly involved through in-vehicle information to influence future or momentary decision making.

CVT is widely expected to provide both public-sector and private-sector benefits, however the incentives of each may not be complimentary. Public-sector benefits of CVT are centralized around safety and mobility improvements while a profit motive exists for the private-sector. Second-order benefits and externalities exist, namely, potential environment benefits, land-use and development impacts, and increased need for cyber-security. Aligning the incentives, costs and public benefit is likely to be a nuanced but achievable challenge.

CVT and AVs are complementary but not necessarily dependent on one another. While they will likely develop closely, CVT is expected to be adopted and deployed more quickly. Adoption will be influenced by several factors including government regulations, price, realized benefits, and market forces. Research demonstrates that motorists are willing to accept CVT applications and vehicle manufacturers are already heavily incorporating these technologies.

Methodology

Overview

The first research question proposed in this Primer—*What is connected vehicle technology, in what applications can it improve safety and congestion outcomes, and what hurdles currently exist related to its adoption?*—has primarily been addressed in the literature review above. The remainder of the Primer largely focuses on the second and third research questions as well as the sub-questions introduced below.

- *How are jurisdictions currently using or testing CVT as a TDM tool?*
    a. *Is CVT being used as a solution for network-wide issues, within individual corridors, or both?*
    b. *What transportation issues is CVT being used to overcome (i.e. safety, mobility, other)?*
    c. *How are the public- and private-sector objectives being aligned to achieve societal goals?*
    d. *What costs and benefits are expected to arise from these projects?*
- *What options are viable tools in the I-70 Mountain Corridor and can contribute to the Coalition's TDM goals?*
    a. *To what degree are existing models applicable or adaptable to this unique corridor?*

To answer these remaining questions, eight real-world case studies of CVT pilot or deployment projects were compiled and analyzed. Two of the pilots (CA and VA) are technically "testbed environments" of which there are at least five others around the country, all of which are affiliated with the USDOT ITS/JPO. One pilot in this study is a national "challenge" lead by the NOCoE and thus facilitates and encourages the deployment of small-scale DSRC and signal phasing and timing (SPaT) buildouts. The pilots within this Primer were chosen to provide a full-range of current models of projects to test CVT applications. The "true" pilots (CO, NY, THEA, UT and WY) account for nearly all of the pilots currently underway in North America.

The case studies are principally informed by primary source information from the projects or the lead jurisdictions, and, when appropriate, secondary sources (Table 1). In some instances, informed public officials and practitioners were contacted through email and phone correspondence to provide context or clarify missing or confusing details of the project.

Table 1: Case Studies & Associated Resources

Project & Location	Data Source	Expert Contact
California: Connected Vehicle Testbed	(California Connected Vehicle Testbed, 2018); (Prospect Silicon Valley, 2018);	N/A
Colorado: "Smart 70" Project	(CDOT, 2018a); (CDOT, 2018b); (Kozinski, 2018)	Peter Kozinski, Director Road X Program, CDOT
New York City: NYDOT/ USDOT Connected Vehicle Pilot	(Galgano et al., 2016); (Talas et al., 2016); (Talas, M., 2017); (USDOT, 2018a); (USDOT, 2018b); (USDOT, 2018c)	N/A
National: SPaT Challenge - NOCoE	(National Operations Center of Excellence, 2018b); (Leonard, 2017a)	N/A
Tampa, Florida: THEA / USDOT Connected Vehicle Pilot	(Johnson et al., 2016); (Novosad, 2018); (USDOT, 2018a); (USDOT, 2018d); (USDOT, 2018e); (Waggoner et al., 2016)	Steve Novosad, Associate Vice President, HNTB
Utah: DSRC MMITSS Project	(Leonard, 2017b); (Leonard, 2018a); (Leonard, 2018b)	Blaine Leonard, Technology & Innovation Engineer, UDOT
Virginia: Connected Corridors (VCC)	(Powell, 2018); (VTTI & VDOT, 2018); (Doerzaph, 2018)	Zac Doerzaph, Director Center for Advanced Automotive Research, VTTI & Jason Powell, Interim Co-Director, Virginia Senate Finance Committee
Wyoming: WYDOT / USDOT Connected Vehicle Pilot	(Ragan, 2018); (Gopalakrishna et al., 2015); (Gopalakrishna et al., 2016); (USDOT, 2018a); (USDOT, 2018f); (USDOT, 2018g)	Ali Ragan, Project Manager, WYDOT

Due to the unique nature of the Corridor and the diverse interests of the Coalition's stakeholders, certain applications of CVT being explored by other jurisdictions will be more helpful than others in achieving the Coalition's TDM strategies.

A qualitative analysis is conducted of the case studies and literature to answer the research questions. Using the framework laid out below, specific variables, chosen to grasp an understanding of the project, are identified. Each of these variables seeks to answer different aspects of the research questions and thus applies uniquely to the hypothesis that the experiences of other jurisdictions can inform Colorado's experience.

Case Study Framework

Table 2 presents a framework that connects the variables, hypotheses, and research questions, allowing for categorization of data and comparison among projects. Full profiles of each of the eight cases are available in Appendix A.

Table 2: Case Study Framework, Content and Topics

Variables	Hypothesis	Research Question
I. Project Parameters • How big (miles, blocks, vehicles, units, etc.) is the project? • Facility Type • What communication technologies are being used and what in what format? • Project Overview	The parameters of other projects will directly inform the level of applicability to the I-70 Mountain Corridor, specifically the facility type.	RQ #2a RQ #2b RQ#3
II. Goals, Objectives & Evaluation • What transportation problems are being targeted (i.e. congestion, safety, other, multi-faceted)? • What strategies are being considered for adaption or future deployment? • What are the realized or sought quantitative benefits? • What are the expected or realized costs of the project? • What second-order benefits or drawbacks may or have arisen?	The goals and objectives of other pilots may or may not corollate closely to the transportation issues facing the I-70 Mountain Corridor. Pilots seeking to solve mobility and safety issues related to highway traffic and weather events will provide the most relevant information.	RQ #1 RQ #2b RQ #2d RQ #3
III. Implementation and non-Governmental Involvement • What is the catalyst for this project (government costs, market/consumer pressures, safety concerns, private interests)? • How are adoption rates being measured, considered or incentivized? • Is the project a proof of concept or full-term solution? • What is the anticipation length or timeline of the project?	The long-term objectives of other pilots are important to learning how CVT will progress nationally. The Coalition can gain perspective from the pace and approach of other pilots.	RQ #1 RQ#2a RQ #2b
IV. Jurisdictional Factors • Who is the lead jurisdiction? • How are impacted (sub) jurisdictions being involved by the lead party? • To what degree and for what purpose is the motoring public being involved? • What is the role of the private-sector? • What efforts are taken to align private- and public-sector incentives?	The I-70 Coalition can benefit most from gleaning lessons learned and observing how other lead jurisdictions seek to involve other parties and to what degree.	RQ #2c RQ #3

Limitations

The accessible data for the pilots in this study are limited in that most of the projects are in the pre-operations or early operational stages. Further, when in operations, many of the projects are seeking to prove concepts or identify potential roadblocks, therefore limited amounts of quantitative data and measured goals are yet available. These circumstances create a limitation on the ability to analyze transportation outcomes. Rather a qualitative analysis is presented to assess how other jurisdictions are approaching CVT, either similarly or dissimilarly to Colorado.

Results

The data is organized across three broad categories—project parameters, goals and objectives, and jurisdictional interactions. Specific aspects within each have been identified to help address the research questions. The jurisdictional interactions category combines aspects of variable III and IV from Table 2.

Project Parameters

Of the eight projects, three (CO, VA and WY) focused primarily on the use of CVT within an Interstate environment, and five primarily involved urban networks or corridors. All eight pilots are testing the use of DSRC communication for either V2I (eight projects), V2V (six projects), V2X (two projects) or a combination of these approaches (six projects). The project sizes vary widely from as little as two miles and 17 intersections (California) to as many as 402 miles (Wyoming), and two urban networks (Tampa and NYC). Traffic counts within the pilots' zones range from 18,000 annual average daily traffic (AADT) to more than 315,000 (AADT). Table 3 below presents details on each pilot's size, facilities and communication approach.

Table 3: Pilot Parameters

Project	Size	Facility Type	Communication Type	Communication Technology
California: Connected Vehicle Testbed	17 signalized intersections; ~2 miles	Signalized Arterial Highway; 50,000 daily trips	V2V & V2I	DSRC and MMITSS
Colorado: "Smart 70" Project	90 miles growing to 500+ miles	Interstate with ~70,000 daily trips; transitioning to other highways	V2V, V2I and undefined others	DSRC and undefined others
New York City: NYDOT/ USDOT Connected Vehicle Pilot	Three urban zones with >300 signalized intersections, > 8,000 vehicles, & > 100 pedestrians	Dense Urban Street Network with 315,000 daily trips	V2V and V2I	DSRC
National: SPaT Challenge - NOCoE	N/A	Urban roadways with signalized intersections	V2I	DSRC
Tampa, Florida: THEA / USDOT Connected Vehicle Pilot	1,600 private vehicles, 10 buses, 10 streetcars and 500+ pedestrians; 1 square mile	Urban Street Network, minimal Interstate; >8,000 daily interstate commuters	V2V, V2I & V2X	DSRC
Utah: DSRC MMITSS Project	11 miles; 35 signalized intersections	Urban Street Corridor with between 18,000 and 60,000 daily trips	V2I	DSRC and MMITSS
Virginia: Connected Corridors (VCC)	60+ Road Side Units (RSUs)	Interstate and some arterial highway	V2V, V2I & V2X	DSRC and Cellular Networks; proprietary cloud
Wyoming: WYDOT / USDOT Connected Vehicle Pilot	402 miles; 75 RSUs and 400 vehicles	Interstate Corridor with 32 million tons of truck freight per year	V2V and V2I	DSRC

Goals & Objectives

While all the pilots seek to further develop CVT and share a long-term goal of large-scale deployment, each project is designed for a specific present need of the lead jurisdictions. In some cases that involves a real-world deployment to solve a pressing transportation issue, while in other instances the project focuses more on research and innovation. Table 4 presents each pilot's structure, targeted issues, costs, timeline and sought benefits.

Table 4: Pilot Goals & Objectives

Project	Format	Targeted Transportation Issue	Costs	Timeline	Sought Benefits & Performance Measures
California: Connected Vehicle Testbed	Testbed	Technology innovation and development	N/A	Created in 2005; updated in 2013; still in operation	Development of new CVT and SPaT applications
Colorado: "Smart 70" Project	Pilot / Public-Private Partnership	Safety, mobility and congestion	$70,000,000	Underway, seeks to have 90-mile buildout within 1.5 years, 500+ miles in 3 years	Safety, mobility, and congestion improvements; develop a cloud-based CV ecosystem for Panasonic to deploy elsewhere
New York City: NYDOT/ USDOT Connected Vehicle Pilot	Pilot (ITS/JPO)	Improve safety of travelers and pedestrians within dense urban environment	$23,500,887	Awarded 9/1/2016; Phase 3 to be completed 10/31/2019	Improved pedestrian safety; will measure fatalities, crashes, red-light violations, bus-related crashes, in-vehicle warning counts, etc.
National: SPaT Challenge - NOCoE	Challenge	Congestion related to signalized intersections; other targeted issues are project specific	N/A – project specific	Goal of 50 state participation by 2020	To encourage the buildout and development of SPaT technologies across the country
Tampa, Florida: THEA / USDOT Connected Vehicle Pilot	Pilot (ITS/JPO)	Commuting related congestion; pedestrian interactions	$19,076,770	Phase 1 began 9/2015; Phase 3 will end 11/2019	Improved commute trip time (to be measured), enhanced traffic flow, improved pedestrian safety (not expected to yield statistically relevant results)
Utah: DSRC MMITSS Project	Pilot	Transit schedule reliability	$1,000,000	Concepted 2014, real-time operations began 10/2017	Seeking to improve transit schedule reliability from 86 to 94 percent
Virginia: Connected Corridors (VCC)	Testbed	Innovation and testing of CVT applications	N/A – project specific	Ongoing with short-term projects	Provide an environment for developers and private-sector to test CVT and identify potential issues
Wyoming: WYDOT / USDOT Connected Vehicle Pilot	Pilot (ITS/JPO)	Safety and incident related congestion	$5,755,972	Operational testing underway, Phase 3 to begin 2018	Targeted: 10% reduction in crashes; 20% reduction in serious injuries & fatalities; 50% reduction in number of vehicles in crashes

The pilots can broadly be divided into three categories based on their stated goals. Two projects (CA and VA) are testbeds with goals focusing on research, innovation and development of technologies in a real-world environment. Three projects (Tampa, NYC, and WY) exist as part of a large project of the USDOT ITS/JPO, with objectives focusing on real-world implementation of CVT while directly informing federal standards and processes. Two projects (CO and UT) exist at the state department of transportation level and seek to produce real-world deployment of CVT. However, the pilot leads are coordinating closely with the USDOT, industry stakeholders, and other public-sector parties to ensure a broad benefit of their development and lessons learned. One pilot (SPaT Challenge) is an outlier in that its purpose is to encourage and assist the deployment of specific CVT applications for signalized intersections.

Jurisdictional Interactions

As with any transportation related project, the pilots exist in environments with multiple stakeholders and public-sector jurisdictions. Markedly, the pilots are almost exclusively unilateral in their public-sector approach, save for the three projects with USDOT ITS/JPO oversight. The relative infancy of CVT appears to be a limiting factor in creating a broad coalition of public jurisdictions in the execution of these pilots.

Private-sector involvement varies among the project. Table 5 presents an overview of the lead jurisdictions and to what degree the private-sector is involved in each pilot.

Table 5: Jurisdictional Factors and Non-Governmental Involvement

Project	Lead	Private-Sector Involvement	Public-Private Incentives
California: Connected Vehicle Testbed	Caltrans	Prospect Silicon Valley, DIGI, Mobil Mark, RSM	Testbed allows for the private sector to test potential applications, development of technologies may lead to public-sector improvements.
Colorado: "Smart 70" Project	CDOT	Panasonic	Public-private partnership (P3) agreement to have Panasonic develop a CV ecosystem to provide safety and mobility benefits to CDOT. Panasonic in turn can market the product to other states/jurisdictions. Third-party access to data for consumer products/services may be allowed. This allows for private sector profit motive while ensuring public-sector goals.
New York City: NYDOT/ USDOT Connected Vehicle Pilot	NYDOT & USDOT ITS/JPO	Taxi and Limousine Commission, United Parcel Service (UPS)	Private sector partners are on the usage side one, public-sector goals are the primary focus with little consumer/market based objectives.
National: SPaT Challenge - NOCoE	NOCoE and AASHTO	Project dependent, none at the challenge level	Project dependent
Tampa, Florida: THEA / USDOT Connected Vehicle Pilot	THEA & USDOT ITS/JPO	Project team includes private sector and academic partners	Goals of the project are distinctly public-sector related, private-sector partners are contracted to meet help accomplish the objectives established by leads.
Utah: DSRC MMITSS Project	UDOT	Utah Transit Authority is quasi-private	No private involvement
Virginia: Connected Corridors (VCC)	VDOT & VTTI	Various	The project's goals centralize around creating an environment for academic researchers and industry developers to test concepts and applications. Private-sector interests are progressed through development of technology with future consumer applications, and private-sector benefits may arise from the accelerated deployment and development of CVT applications.
Wyoming: WYDOT / USDOT Connected Vehicle Pilot	WYDOT & USDOT ITS/JPO	Contract team includes private partners for development.	A CV Pilot Freight Advisory Committee (FAC) has been created to have multiple parties at the table when evaluating the pilot and identifying future applications and deployment decisions. Goals are to increase safety and limit blow overs which are directly beneficial to the trucking industry.

Three projects (CO, NY and WY) involve third parties, to some degree, in the on-the-road operations of vehicles either through equipping commercial fleet vehicles or involvement through an advisory board. The two testbeds (CA and VA) primarily exist to provide academic and industry researchers access to a CVT environment. Colorado's pilot is unique in that a private partner, Panasonic, is a direct partner of CDOT. One stated outcome of the partnership is for Panasonic to come away with a large-scale, ready-for-market proprietary product.

Discussion & Recommendations

The CVT pilots analyzed in this Primer have limited operational experience to date. Thus, it is difficult to ascertain complete lessons learned. However, many similarities and trends can be identified and highlighted for the Coalition to consider.

Research Question 1: CVT Applications

While the literature review chiefly focused on answering Research Question 1—*What is connected vehicle technology, in what applications can it improve safety and congestion outcomes, and what hurdles currently exist related to its adoption?*—the research findings provide evidence of important practical realities of CVT.

As discussed in the literature review, the principle public-sector benefits center around safety and mobility applications, either through backend transportation management approaches or in-vehicle interventions. We see both approaches used in the pilots. Colorado, New York City, Tampa and Wyoming plan to incorporate a mix of backend planning applications and in-vehicle interventions in their CVT deployments. Conversely, Utah and the SPaT Challenge projects will use CVT for backend planning operations only.

The literature suggests several communication technologies are candidates for conducting CVT, however, all off the pilots examined will use DSRC as the main communication tool, with two (CA and UT) incorporating MMITSS software and Virginia testing cellular network feasibility. Notably, Colorado's approach is to design a "CV ecosystem" with interoperability with any future communication technology and application (Kozinski, 2018). This approach, while aggressive, may provide future gains and efficiencies as innovation continues.

Research Question 2

Facility type & transportation issues.

At the technology level, all the pilots collectively will progress the development of communication technologies and the troubleshooting of unforeseen circumstances. However, at the operations level, applications being tested within urban networks will translate marginally to the Corridor. Intersection conflicts and pedestrian issues faced within an urban network are of prime concern in the NYC and Tampa pilots, but irrelevant to an Interstate environment.

Most relevant in terms of facility type and transportation issues to the Corridor are the pilots in Virginia and Wyoming. The technology and applications being tested within the VCC may soon benefit travelers and commuters on I-70 and other Interstates. It is prudent for CDOT and other Colorado stakeholders (both public and private) to pay close attention to Wyoming's pilot and its performance measures. If the targeted crash avoidance goals are achieved, the safety implications and decreased incident-related congestion would be tangible benefits desired within the Corridor. The specific adherence to weather related issues in Wyoming's pilot are highly relevant to Colorado's winter traffic and safety concerns.

Private-sector involvement.

As discussed in the literature review, perspectives on the outcomes of CVT can vary depending on the parties involved. Public-sector officials will likely have markedly different motives and incentives than industry and the motoring public. Although all three groups likely share some desired outcomes.

Of the pilots examined, Colorado's approach reflects the California and Virginia testbeds most closely in terms of private-sector involvement and incentives. Whereas they provide real-world environments to test and develop nascent technologies, the Smart 70 Project creates a similar circumstance for Panasonic. This is not to infer that CDOT is absolving itself of meaningful contributions or oversight of the pilot, but rather to highlight the innovative approach to allow greater private-sector involvement in the creation, implementation and lifecycle of CVT on Colorado's roads. Under this model, the private-sector gains greater access to a real-world environment and can directly contribute to deployment decisions and outcomes. Through this increased access, an opportunity for a consumer-based product arises for the private-sector, allowing for market-based incentives to arise where they otherwise may not.

Utah and the SPaT Challenge are notably strictly focused on the public-sector. UDOT is operating CVT technology in the Redwood Road corridor with only a traditional DOT/contractor relationship. The SPaT Challenge encourages and enables projects that may involve an enhanced private-sector role but its approach is agnostic to that nexus.

Costs and benefits.

At $70,000,000, Colorado's CVT pilot carries, by far, the largest cost in terms of dollar figures. New York City's pilot is the next most expensive at $23,500,887. Utah's DSRC MMITSS project is significantly cheaper at approximately $1,000,000. However, the expected life-span of Colorado's deployment is dramatically longer and the associated size is much larger than the others. While the ITS/JPO associated pilots (NYC, Tampa and WY) are scheduled to end in late 2019, Colorado's pilot seeks to deploy its CV ecosystem permanently. Further, through the P3 agreement, CDOT will receive free upgrades and enhancements to the system as further technologies are developed. CDOT's three-year goal of more than 500 connected miles of roadway is larger, in terms of mileage, than any other pilot currently underway.

Measurable benefits are largely absent within the pilot projects to date. Although, performance measures have been identified for some of the pilots. As discussed previously, the uniqueness of the Corridor creates limitations to the applicability of some CVT applications being tested nationally. Specifically, the focus on urban networks by New York City and Tampa are less translatable to the Corridor while Virginia and Wyoming's focus on Interstate facilities, freight traffic, and weather-related incidents apply more readily.

Research Question 3: Takeaways, Recommendations and Limitations for the I-70 Coalition

Colorado is currently deploying one of the largest and most ambitious CVT pilots in the nation, both in anticipated scale and comprehensiveness. If successful, the associated benefits may improve congestion and safety issues plaguing the Corridor. However, due to the infancy of CVT and the early stages of other pilots across the country, conclusions are yet to be drawn or confidently assumed.

Jurisdictional roles.

While considering the other active pilots, the most striking finding, as it relates to the Coalition, is the unilateral approach of the exploration of CVT. The nascent nature of CVT creates difficulties for moving forward with a wide coalition of jurisdictions. Nevertheless, the lack of interjurisdictional roles should not act as a roadblock to the development of CVT. Each pilot individually has targeted certain desired benefits according to the particular transportation issues facing its environment, and these transportation issues do not impact just one single jurisdiction. Therefore, the support of impacted jurisdictions can encourage the proper studying and testing of new technologies to ensure public safety and benefit before a full-scale deployment occurs.

While CDOT indicated no immediate formal role for municipalities, counties or other parties in the Smart 70 Project, it is still prudent for the Coalition and its members to actively seek out future opportunities for partnering with CDOT. Further, communication strategies focused on CVT education and awareness, both to public officials and travelers, will contribute to a more prepared motoring public when wider deployment occurs.

TDM management.

Both the literature and the case study data provide insight in to the potential ability of CVT to serve as a TDM tool for the Coalition. Safety and mobility applications are certainly important to the Coalition and critical for improving the public-benefit. However, consumer focused CVT applications, of which the private-sector views as marketable services, may provide an enhanced channel for furthering the Coalitions TDM strategies.

The “infotainment” potential (as identified by IBM) of CVT may create opportunities for strategies such as traveler education and outreach, partnerships with businesses and industry, and promotion of TDM strategies via other organizations. The majority of the CVT applications being tested within the pilots, focus on managing vehicles on the roadway. The case studies provided few examples of intervention of a person’s decision to make a trip or drive a single occupancy vehicle.

Discussed previously, Viereckl et al. (2015) found that motorists expressed a greater preference for consumable information related to their current or future trips than compared to information about their vehicle such as performance statistics (as cited in Coppola & Morisio, 2016). Third-party applications, leveraging CVT data, could be used to create such an intervention, either through the promotion of carpooling or transit options or consumer benefits from private-sector partners.

Conclusion

There is broad support and belief in the potential benefits of CVT across academic, public-sector and private-sector stakeholders. Viewed by many as a precursor to AV technology, CVT carries the potential to revolutionize our transportation systems while opening the door to an even more significant technology.

While many conceptual benefits of CVT exist, most pertinent to departments of transportation and policymakers are the potential safety and mobility improvements. Through a V2V, V2I or V2X, DOTs can create an environment of robust data collection and sharing with the intent to directly or indirectly intervene in the driving process in hopes to mitigate common transportation conflicts such as crashes, delays due to inclement weather, work zone conflicts, human distraction and others.

Technological proof-of-concept may be the last big hurdle to fully deploying CVT applications and overcoming the “chicken or the egg” problem whereas investing public monies into CVT systems is dubious when the technology is yet to be fully refined and developed.

In this regard, pilot projects and testbeds create the environment to progress and advance technologies and allow innovation to occur. Broad support of these pilots is crucial to ensuring their success in determining the value of CVT and potential public benefits. From the analysis in this Primer, it is unclear whether a role for sub-jurisdictions (such as cities, towns and counties in Colorado’s case) should play a significant role in CVT pilots, however, the support of such jurisdictions will be critical for a full-scale deployment. Therefore, it is prudent for such parties to be apprised of current advancements of CVT and deployment efforts nationally.

The primary short-term goal of the Coalition is the implementation of non-infrastructure improvements and TDM strategies. Based on the applications being explored through the examined pilots, the TDM strategies of the Coalition can be enhanced. In its most basic form, CVT enhances traveler education and outreach, the Coalition’s first stated strategy. Through private-sector involvement, the remaining strategies can be enhanced.

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Appendix A: Case Studies

California CV Testbed	
Project Parameters	
Project Size / Mileage:	17 signalized intersections along 2+ miles
Facility Type:	Testbed; State Route 82, signalized arterial highway serving more than 50,000 vehicles each day
Communication Type:	V2V and V21 via Multi-Modal Intelligent Traffic Signal Systems (MMITSS) and DSRC
Project Overview:	California's CV Testbed, a collaboration between Caltrans, the Metropolitan Transportation Commission and the California Berkley PATH program, was the nation's first connected vehicle testbed. Originally created in 2005, the project was updated in 2013 to meet current technology and standards. The project was expanded from 11 to 17 intersections with the intent of testing MMITSS and environmentally-friendly driving applications.
Goals, Objectives & Evaluation	
Existing problem to overcome:	Technology innovation and development
Future adaption or adjustment:	The testbed recently expanded and continues to operate. It seeks to act as a model for other deployments in California or around the country.
Primary potential benefits:	Development of new CVT and SPaT applications.
Expected or realized costs:	State and federal funding
Second-order benefits:	Testing of environmentally-friendly driving applications.
Implementation and non-Governmental Involvement	
Project catalyst:	First in the nation to test DSRC and wireless communication among vehicles and infrastructure and a real-world environment.

Adoption rates:	N/A
Project length & depth:	Began in 2005 and still under operation.

Jurisdictional Factors	
Lead jurisdiction:	The California Department of Transportation (Caltrans)
Sub jurisdictions involved & role:	
Public involvement:	
Private sector involvement:	Private partners include Prospect Silicon Valley, DIGI, Mobile Mark and RSM.
Public-Private nexus:	A memorandum of operations was signed with Prospect Silicon Valley to allow for increased access to the testbed by private-sector developers in order to further conduct real-world testing and advance new safety, congestion and environmental applications.
Sources:	(California Connected Vehicle Testbed, 2018); (Prospect Silicon Valley, 2018);

Colorado "Smart 70" Project

Project Parameters	
Project Size / Mileage:	Initially proposal is for a project on I-70 between Golden, CO and Vail, CO; approximately 90 miles; Long-term (3 years) CV environment will be scaled to 500+ miles
Facility Type:	Pilot; Interstate 70 Mountain Corridor with future growth to other highways
Communication Type:	DSRC to begin, however the CV ecosystem being created will be communication technology agnostic in order to adapt to future technology and applications. A secondary partnership created a smartphone navigation app via cellular networks.

Project Overview:	The Smart 70 Project is a public-private partnership between CDOT and Panasonic with the goal of developing and deploying a CV ecosystem. The final ecosystem will be capable of conducting the “full range” of current or furture applications of CVT. Within 1.5 years, the ecosystem will be deployed throughout the I-70 Mountain Corridor (90 miles). As many as 100 RSUs will be intalled along the corridor and up to 2000 OBUs will be installed into CDOT fleet vehicles and other state partners. The general public will not initially be connected to the ecosystem. After 3 years, the CV ecosystem will be fully developed and CDOT hopes to have it deployed across 500+ miles of roadways across the state. After development, Colorado will license and intellectual property to Panasonic who will then be able to take the ecosystem product to market for deployement in other states and jurisdictions. Colordao will receive free upgrades and adjustments as future developments or applications are created by Panasonic. A primary goal is to create a “cloud-based” ecosystem that will be approximately 95% software based and 5% hardware—such as on-board units (OBUs) and road-side units (RSUs)—based. The project will focus on interoperability and being communication techonlogy agnostic with hopes of creating a product that is adaptable across jurisdictions and future techonlogies.
Goals, Objectives & Evaluation	
Existing problem to overcome:	Safety, mobility and congestion issues on I-70 due to heavy usage and weather events. Seeks to improve trip reliability within Colorado’s limited freight corridors (I-70 and ultimately, I-25).
Future adaption or adjustment:	As the CV ecosystem is further developed by Panasonic through future deployments in other states, Colorado will receive free upgrades and improvements as part of their contractual agreement. Ultimate goal is to develop and test a V2I and V2V system that is fast and accurate enough to be used by

	automated vehicles and under any future conceivable application of CVT.
Primary potential benefits:	Safety, mobility, trip reliability improvements within major transportation corridors in the state.
Expected or realized costs:	Contract with Panasonic is $70,000,000.
Second-order benefits:	Environmental benefits may arise due to decreased congestion.
Implementation and non-Governmental Involvement	
Project catalyst:	Safety and congestion issues on the corridor.
Adoption rates:	Initial deployment will include 100 RSUs along the 90-mile corridor, 2,000 OBUs (state fleets or "friends and families") as part of the contracted work with Panasonic. Other states are in pre-purchase agreement with Panasonic to roll out further. Adoption by the public will likely develop via consumer products provided by Panasonic and other private-sector parties tapping into the CV ecosystem's data and information.
Project length & depth:	Estimated to have the 90 miles within the I-70 Mountain Corridor deployed in 1.5 years. After 3 years, the full ecosystem will be created by Panasonic and Colorado plans to have 500+ miles of roadway connected across the state.
Jurisdictional Factors	
Lead jurisdiction:	Colorado Department of Transportation
Sub jurisdictions involved & role:	No concurrent effort between CDOT and localities to use the ecosystem. As the project is implemented localities will be able to use data collected to develop further applications or use within their transportation planning efforts. There are currently no plans to mandate the use of the ecosystem by localities. CDOT has also been working closely with USDOT's Intelligent Transportation Systems Joint Programs Office

	(ITS/JPO) to ensure development is in line with the federal efforts within the CVT space.
Public involvement:	Limited involvement of the motoring public. Within the initial project, no public vehicles will be equipped with OBUs. However, Panasonic and other vendors will likely have market-based efforts to sell services and products to the motorists.
Private sector involvement:	Panasonic is the private-sector lead and contacted with CDOT. Other private-sector parties are involved with the project under Panasonic's umbrella but not currently publicly disclosed. CDOT has partnered with HERE for the creation of a smartphone app that will provide real-time information from other app users. This is a separate effort from the Panasonic CV ecosystem being developed.
Public-Private nexus:	No incentives yet tied to benchmarks for performance. CDOT's goals will be achieved by the creation of the CV ecosystem and Panasonic will have the ability to market the product to sell to other jurisdictions or states.
Sources:	(CDOT, 2018a); (CDOT, 2018b); (Kozinski, 2018)

New York City, New York / US DOT Connected Vehicle Pilot

Project Parameters	
Project Size / Mileage:	Pilot encompassed three zones within Manhattan and Brooklyn. Multiple miles of corridors within these zones will be targeted which include more than 300 signalized intersections. Approximately 5,800 taxis, 1,250 MTA buses, 400 commercial fleet delivery trucks, and 500 city fleet vehicles will be outfitted with CV communication technology. As many as 350 RSUs will be installed along the corridors and nearly 40 RSUs will be deployed outside the immediate pilot zones at critical travel points such as bridges and tunnels. Approximately 100 pedestrians will be equipped with devices to communicate to vehicles and provide pedestrian warnings to the motorists. Anticipated to be the largest CVT deployment to date.
Facility Type:	Pilot; Dense urban environment; 315,000+ average annual daily traffic (AADT)
Communication Type:	V2V and V2I via DSRC
Project Overview:	The NYCDOT / US DOT Connected Vehicle Pilot is one of three demonstration projects under the USDOT's Intelligent Transportation Systems Joint Program Office. The goal of the CV pilot deployment program is to encourage and facilitate innovative among early CVT adopters across a variety of applications. Specifically, the NYCDOT pilot will focus on pedestrian safety and vehicle-pedestrian interactions. By equipping more than 8,000 vehicles (fleet trucks and taxis), as well as pedestrians, the pilot seeks to compliment NYC's Vision Zero efforts which focus on minimizing vehicle-related injuries and deaths. V2V applications include in-cab warnings to drivers of various potential hazards including forward crash warning, break light warnings, blind spot warnings, lane change warnings and others. V2I applications include speed compliance, curve speed compliance, work zone speed compliance, red light warning, oversize vehicle compliance and others. Pedestrian applications include priority signalized crosswalks and mobile accessible signal systems.

Goals, Objectives & Evaluation

Existing problem to overcome:

Seeking to improve safety of travelers and pedestrians within the urban environment.

Future adaption or adjustment:

The pilot will significantly inform future CVT applications within a high-density environment with many intersections and conflict points.

As part of the ITS/JPO pilot program, the pilot will inform future CVT standards and deployment efforts.

Primary potential benefits:

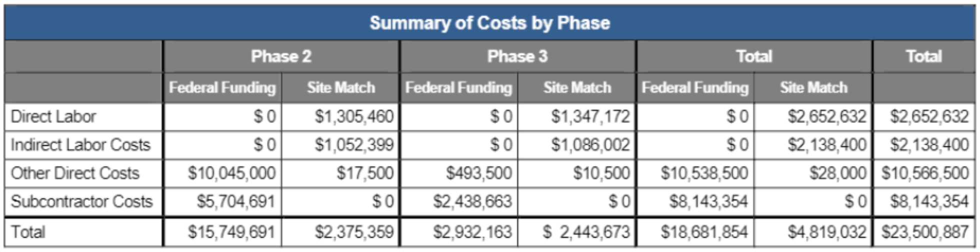
Pedestrian and traveler safety; performance metrics will include fatality and injury crash counts, property damage crash counts, red light violation counts, driver actions in response to alerts, bus related crash counts, number of warnings generated, right-turn related conflicts.

Expected or realized costs:

Assuming 8,000 equipped vehicles, the per vehicle cost will be approximately $2,938.

Overall (all phases) costs will be $23,500,887; of which $18,681,854 is federal funding and $4,819,032 is local match.

Table 6-1. High Level Costs by Phase



Summary of Costs by Phase

	Phase 2		Phase 3		Total		Total
	Federal Funding	Site Match	Federal Funding	Site Match	Federal Funding	Site Match	
Direct Labor	$ 0	$1,305,460	$ 0	$1,347,172	$ 0	$2,652,632	$2,652,632
Indirect Labor Costs	$ 0	$1,052,399	$ 0	$1,086,002	$ 0	$2,138,400	$2,138,400
Other Direct Costs	$10,045,000	$17,500	$493,500	$10,500	$10,538,500	$28,000	$10,566,500
Subcontractor Costs	$5,704,691	$ 0	$2,438,663	$ 0	$8,143,354	$ 0	$8,143,354
Total	$15,749,691	$2,375,359	$2,932,163	$ 2,443,673	$18,681,854	$4,819,032	$23,500,887

Image Source: (Talas et al., 2016, pg. 66).

Second-order benefits or impacts:

Potential negative impact is in-cab distraction of drivers or drivers ignoring multiple notifications. Potential issues may arise during overly congestion travel times and low travel speeds.

Implementation and non-Governmental Involvement

Project catalyst:

The project is aligned with NYC's Vision Zero initiative which included a citywide speed limit (25 mph) seeking to minimize pedestrian deaths.

Adoption rates:

N/A – no adoption outside of the pilot's participants

Project length & depth:

The award date was 9/1/2016 and phase 3 will be completed on 10/31/2019.

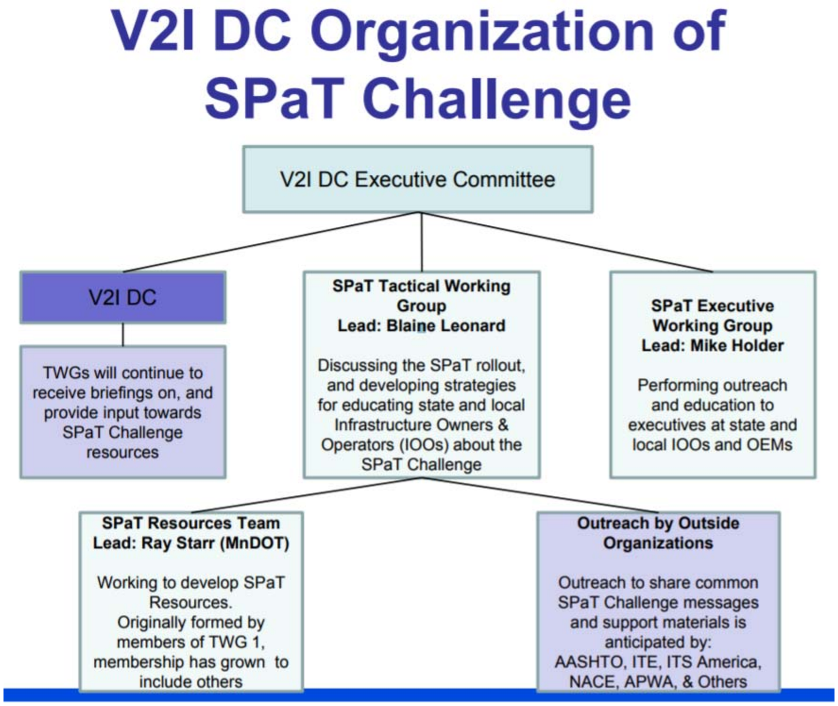
Jurisdictional Factors

Lead jurisdiction:	New York City Department of Transportation (NYCDOT)
Sub jurisdictions involved & role:	Public-sector partners include NYC Department of IT, NYC Department of Sanitation, NYC Transit and the Metropolitan Transportation Authority (MTA)
Public involvement:	
Private sector involvement:	The pilot directly includes taxis from the Taxi and Limousine Commission fleets as well as trucks from the United Parcel Service (UPS). Private-sector firms are contracted as part of the project team, however no private-sector applications are apparent in the deployment of the pilot.
Public-Private nexus:	Public-sector goals are the primary focus with minimal involvement of private-sector or consumer based objectives.
Sources:	(Galgano et al., 2016); (Talas, M., 2017); (Talas et al., 2016); (USDOT, 2018a); (USDOT, 2018b); (USDOT, 2018c)

Image Source: (USDOT, 2018c).

Signal Phasing and Timing (SPaT) Challenge – National Operations Center of Excellence (NOCoE), American Association of State Highway and Transportation Officials (AASHTO)	
Project Parameters	
Project Size / Mileage:	A single corridor or a network with at least 20 signalized intersections.
Facility Type:	Pilot; Corridor or Urban Network
Communication Type:	V2I through DSRC
Project Overview:	The SPaT Challenge is a program geared towards state and local public-sector owners of transportation infrastructure. The goal is to encourage and facilitate cooperation among infrastructure owners to develop and deploy DSRC technology on a corridor scale. Ultimately the challenge seeks to have DSRC and SPaT technology deployed in at least one corridor or network (at least 20 signalized intersections) in each of the 50 states by 2020. Three projects are operational within the Mountain West, Utah's University Parkway, Las Vegas, Nevada's Freemont Street, and a network in Anthem, Arizona. One project is underway in Colorado, Arapahoe Road in the southeast Denver Metro. An additional project of note is an effort scheduled to be operational in late Summer 2018 along Wyoming's I-80 corridor which will phase signals near truck stops and complement WYDOT's I-80 CV Pilot.
Goals, Objectives & Evaluation	
Existing problem to overcome:	Challenge guidelines are not specific to one type of transportation problem for which a solution should be sought. Rather, an owner may presumably seek to deploy DSRC communications at signals to alleviate any number of transportation issues (safety, congestion, mobility, etc.).
Future adaption or adjustment:	Project dependent
Primary potential benefits:	Encouraging early deployment of DSRC and CV technologies.
Expected or realized costs:	N/A – likely to vary widely per project

Second-order benefits:	Project dependent
Implementation and non-Governmental Involvement	
Project catalyst:	Seeking to overcome the "chicken and egg" problem of deploying CVT when demand will be driven by the deployment.
Adoption rates:	Officially as of April 2017, 4 agencies have active DSRC SPaT system and another 13 jurisdictions are actively pursuing the SPaT challenge. Updated 2018 (unlabeled date), at least 11 deployments are operational and more than 20 others are underway.
Project length & depth:	Currently active and seeking to meet challenge by January 2020.
Jurisdictional Factors	
Lead jurisdiction:	NOEoC and AASHTO administered the SPaT Challenge but individual localities or states will lead individual projects.



V2I DC Organization of SPaT Challenge

V2I DC Executive Committee

V2I DC

TWGs will continue to receive briefings on, and provide input towards SPaT Challenge resources

SPaT Tactical Working Group
Lead: Blaine Leonard

Discussing the SPaT rollout, and developing strategies for educating state and local Infrastructure Owners & Operators (IOOs) about the SPaT Challenge

SPaT Executive Working Group
Lead: Mike Holder

Performing outreach and education to executives at state and local IOOs and OEMs

SPaT Resources Team
Lead: Ray Starr (MnDOT)

Working to develop SPaT Resources.
Originally formed by members of TWG 1, membership has grown to include others

Outreach by Outside Organizations

Outreach to share common SPaT Challenge messages and support materials is anticipated by: AASHTO, ITE, ITS America, NACE, APWA, & Others

Image Source: (Leonard, 2017a, slide 6).

Sub jurisdictions involved & role:	Various other jurisdictions are likely involved for each project.

Public involvement:	Project dependent
Private sector involvement:	Project dependent
Public-Private nexus:	Project dependent
Sources:	(National Operations Center of Excellence, 2018b); (Leonard, 2017a)

Tampa, Florida / US DOT Connected Vehicle Pilot

Project Parameters	
Project Size / Mileage:	The 1 square mile pilot deployment area resides within downtown Tampa. The pilot will involve 1,600 privately owned vehicles with OBUs, 10 buses with OBUs, 10 streetcars with OBUs, 500+ pedestrian participants (via smartphone app) and 40 RSUs at intersections.
Facility Type:	Pilot; Urban street network, including transit and pedestrian facilities; 8,000 commuters per day arriving in pilot zone via expressway
Communication Type:	V2I, V2V and V2x (pedestrians) via DSRC communication
Project Overview:	The THEA / US DOT Connected Vehicle Pilot is one of three demonstration projects under the USDOT’s Intelligent Transportation Systems Joint Program Office. The goal of the CV pilot deployment program is to encourage and facilitate innovative among early CVT adopters across a variety of applications. Specifically, the THEA pilot seeks to create a connected urban environment in which automobiles, transit vehicles and pedestrians will interact through CVT. A variety of traffic situations will be influenced by this communication with the goal of improving safety and decreasing congestion.

Goals, Objectives & Evaluation

Existing problem to overcome:	Commuting related congestion within Tampa's urban core.
Future adaption or adjustment:	A regional CV Task Force was created in-part to explore future applications of CVT. As part of the ITS/JPO pilots with USDOT, the project will contribute to the development of CV standards and inform future projects in other jurisdictions.
Primary potential benefits:	Improving commuting trip times (to be measured), enhancing traffic flow (to be measured), and pedestrian safety (not expected to provide statically relevant number of interactions)
Expected or realized costs:	Total budget for the pilot is $19,076,770. $15,178,762 comes from federal grants and $3,897,999 is a local match (20 percent) $16,004,317 (84 percent) of the budget is categorized as professional services; $3,072,444 (16 percent) is categorized as materials
Second-order benefits:	Reduced greenhouse gas emissions; conversely cyber-security issues will be created
Implementation and non-Governmental Involvement	
Project catalyst:	Commuter related congestion and pedestrian safety; morning backups, wrong-way incidents, pedestrians, transit priority and conflicts, and traffic flow will all be targeted for improvements and measurable outcomes.
Adoption rates:	THEA will track participation rates on a regular schedule.
Project length & depth:	Pilot project; Phase 1 began in September 2015, Phase 3 will end November 2019
Jurisdictional Factors	
Lead jurisdiction:	Tampa-Hillsborough Expressway Authority (THEA)
Sub jurisdictions involved & role:	A regional CV Task Force will be created by THEA, the City of Tampa, the Florida Department of Transportation and primary partners. This task force will ensure a regional approach and interoperability for potential future applications or expansion.

Public involvement:	The motoring public will be heavily involved with at many as 1,600 privately owned vehicles and 500+ pedestrians connected to the pilot.
Private sector involvement:	The project team includes private sector firms (HNTB, Siemens, Brandmotion, etc.) and academic partners (University of South Florida and Hillsborough Community College).
Public-Private nexus:	Goals of the project are distinctly public-sector related, private sector partners are contracted to meet the objectives of the pilot project as determined by USDOT and THEA.

Sources:	(Johnson et al., 2016); (Novosad, 2018); (USDOT, 2018a); (USDOT, 2018d); (USDOT, 2018e); (Waggoner et al., 2016)

Image Source: (USDOT, 2018d).

Utah DSRC MMITSS Project

Project Parameters

Project Size / Mileage:	11 miles
Facility Type:	Pilot; Arterial Highway Corridor
Communication Type:	V2I using DRSC and Multi-Modal Intelligent Traffic Signal Systems (MMITSS) Software
Project Overview:	The project will focus on transit priority and schedule reliability on Redwood Road. This 11-mile corridor contains 35 signalized intersections, ranges from five lanes up to seven lanes, serves between 18,000 AADT and 60,000 AADT, and trucks make up approximately 24 percent of traffic.
Goals, Objectives & Evaluation	
Existing problem to overcome:	Mobility focused. Transit schedule reliability within a particular corridor and bus route.
Future adaption or adjustment:	One goal of the project is to provide the groundwork for a larger CVT deployment in the future. It will create some of the needed V2I infrastructure needs while adoption levels are minimal but will prepare Utah for wider deployment when adoption levels rise.
Primary potential benefits:	Seeking to increase schedule reliability from 86 percent to 94 percent on bus route 217.
Expected or realized costs:	Costs will occur within five distinct categories: hardware procurement, initial evaluation and testing of hardware, hardware installation, software modification and testing, and project management. Total project costs are slightly more than $1,000,000. The project seeks to carry minimal impact on other traffic in the corridor.
Second-order benefits:	By investing in the buildout of a DRSC network, adoption by the private sector may be stimulated and future deployment efforts may be accelerated.
Implementation and non-Governmental Involvement	
Project catalyst:	UDOT was seeking to develop a DSRC network with the goals of proving the concept, solving a transportation

	issue, and preparing for future deployment and applications.
Adoption rates:	N/A – pilot consists of only public transit buses.
Project length & depth:	This is a fully operational, real-world project which began in 2014. A demonstration portion of the project was completed in February 2017 and real-time operation began in October 2017.
Jurisdictional Factors	
Lead jurisdiction:	Utah Department of Transportation (UDOT)
Sub jurisdictions involved & role:	Redwood Road is state owned but crosses five municipal jurisdictions. UDOT takes precedent on signal operations at intersections with other jurisdiction's roads and the municipalities had no involvement with the project. Utah Transit Authority owns the buses and agreed to be part of the project but other than minimal in-kind labor, they have not been actively involved.
Public involvement:	The motoring public is minimally involved due to no real role for them. The public does receive benefits in the form or greater transit reliability, but potential negative impacts due to increased wait times at some signals when buses are present.
Private sector involvement:	The buses are quasi-public due to the nature of the Utah Transit Authority, but other than that there is no active private-sector involvement.
Public-Private nexus:	N/A
Sources:	(Leonard, 2017b); (Leonard, 2018a); (Leonard, 2018b)

Image Source: (Leonard, 2018b).

Virginia Connected Corridors (VCC)	
Project Parameters	
Project Size / Mileage:	60+ RSUs
Facility Type:	Testbed; Interstate and some other highways
Communication Type:	V2X (everything) via DSRC and cellular networks along with a dedicated VCC Cloud
Project Overview:	VDOT and VTTI have partnered to create the Virginia Connected Corridors and create a unique CVT communication environment for demonstration and prototypes to be tested and deployed. Researchers and developers can access the network of RSUs and CVs to explore emerging applications and technologies. The VCC program seeks to efficiently identify emergent issues and applications in order to proactively seek solutions before full deployment of CVT applications.

	Examples of projects currently being conducted include: active traveler information and demand notifications to CVs on the I-66 corridor; pothole detection; road and surface air temperature reporting via state-owned vehicles; mobile apps for inter-vehicle communications; work zone information distribution via mobile apps; signal phase and timing (SPaT); and others.
Goals, Objectives & Evaluation	
Existing problem to overcome:	CVT is a nascent industry and the VCC seeks to "identify big lessons quickly…to navigate an optimal solution".
Future adaption or adjustment:	Applications and projects piloted in the VCC will directly inform larger-scale future deployment.
Primary potential benefits:	Efficient process to test CVT applications and cost effectively identify any issues prior to market.
Expected or realized costs:	N/A – project dependent
Second-order benefits:	
Implementation and non-Governmental Involvement	
Project catalyst:	Research and development of new CVT applications and systems.
Adoption rates:	N/A
Project length & depth:	Ongoing with short-term pilots
Jurisdictional Factors	
Lead jurisdiction:	Virginia Department of Transportation (VDOT) and the Virginia Tech Transportation Institute (VTTI)
Sub jurisdictions involved & role:	N/A – project dependent
Public involvement:	N/A – project dependent
Private sector involvement:	The project will create a connected and automated vehicle "application development environment" for researchers and third-party developers to access for demonstration and development purposes.

Public-Private nexus:	Allows for public and private stakeholders to research
Sources:	(Doerzaph, 2018); (Powell, 2018); (VTTI & VDOT, 2018)

Wyoming DOT / US DOT Connected Vehicle Pilot	
Project Parameters	
Project Size / Mileage:	402 miles of I-80; 75 roadside units; 400 vehicles with on-board units (OBUs)
Facility Type:	Pilot; Interstate corridor which carries 32 million tons of freight annually; up to 70 percent truck traffic
Communication Type:	V2V and V2I through DSRC communication
Project Overview:	The WYDOT / US DOT Connected Vehicle Pilot is one of three demonstration projects under the USDOT's Intelligent Transportation Systems Joint Program Office. The goal of the CV pilot deployment program is to encourage and facilitate innovative among early CVT adopters across a variety of applications. Specifically, the WYDOT pilot seeks to mitigate safety and mobility issues related severe weather events experiences within the I-80 corridor across Southern Wyoming. Using DSRC communication, 400 vehicles will be connected through V2V and V2I applications.
Goals, Objectives & Evaluation	
Existing problem to overcome:	Safety and incident-related congestion events.
Future adaption or adjustment:	The collection of data from the program will be directed incorporated into WYDOT's long-term transportation demand management practices.

Primary potential benefits:

Expected to reduce the number of truck blow-overs, more than 200 of which have been recorded within the corridor in the past 4 years. Seeks to minimize incident-related delays.

Target of 10 percent reduction in crashes as compared to the 5-year average;
Target of 20 percent reduction in serious injuries and fatalities as compared to 5-year average;
Target of 50 percent reduction in number of vehicles involved in major crashes as compared to 5-year average.

Expected or realized costs:

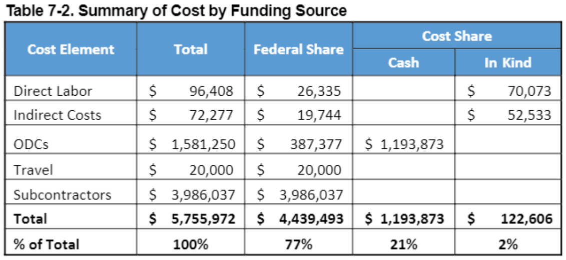


Table 7-2. Summary of Cost by Funding Source

Cost Element	Total	Federal Share	Cost Share	
			Cash	In Kind
Direct Labor	$ 96,408	$ 26,335		$ 70,073
Indirect Costs	$ 72,277	$ 19,744		$ 52,533
ODCs	$ 1,581,250	$ 387,377	$ 1,193,873	
Travel	$ 20,000	$ 20,000		
Subcontractors	$ 3,986,037	$ 3,986,037		
Total	**$ 5,755,972**	**$ 4,439,493**	**$ 1,193,873**	**$ 122,606**
% of Total	**100%**	**77%**	**21%**	**2%**

Total pilot cost is $5,755,972 of which the federal share is $4,439,493 and WYDOT's match is $1,316,477 (23 percent).

Image source: (Gopalakrishna et al., 2016, pg. 78).

Second-order benefits or costs:

Automatic collection of road weather data from snow plows and other DOT vehicles will lead to better historical data for future TDM efforts. Mobility improvements for all drivers will likely occur with safety improvements.

Implementation and non-Governmental Involvement

Project catalyst:

The corridor can experience frequent severe weather events which create unsafe travel conditions. These events can lead to negative safety impacts and incident related delays.

Adoption rates:

N/A; limited to 400 fleet, state and commercial vehicles.

Project length & depth:

Operational testing, demonstration and WYDOT fleet operation are currently underway; Phase III to begin May 2018.

Jurisdictional Factors

Lead jurisdiction:

Wyoming Department of Transportation (WYDOT)

Sub jurisdictions involved & role:

United States Department of Transportation (USDOT)

Public involvement:	The driving public is not directly involved, a portion of the 400 equipped vehicles will be private sector fleet vehicles and commercial trucks.
Private sector involvement:	WYDOT is the overall lead and responsible for the project governance and implementation. Contractor team includes ICF, Trihydo, University of Wyoming, McFarland Management. Vital Assurance, NCAR, and CV Vendors. Other involved parties include fleet partners, in-state academic and governmental bodies, adjacent state DOTs and independent evaluators. The project will deliver inherently public-sector and motorists benefits but data will be available to third parties for further development and applications.
Public-Private nexus:	A CV Pilot Freight Advisory Committee (FAC) will be created to advise the pilot on future development and posts-pilot operations. However, the FAC has yet to meet to date.
Sources:	(Gopalakrishna et al., 2015); (Gopalakrishna et al., 2016); (Ragan, 2018); (USDOT, 2018a); (USDOT, 2018f); (USDOT, 2018g)

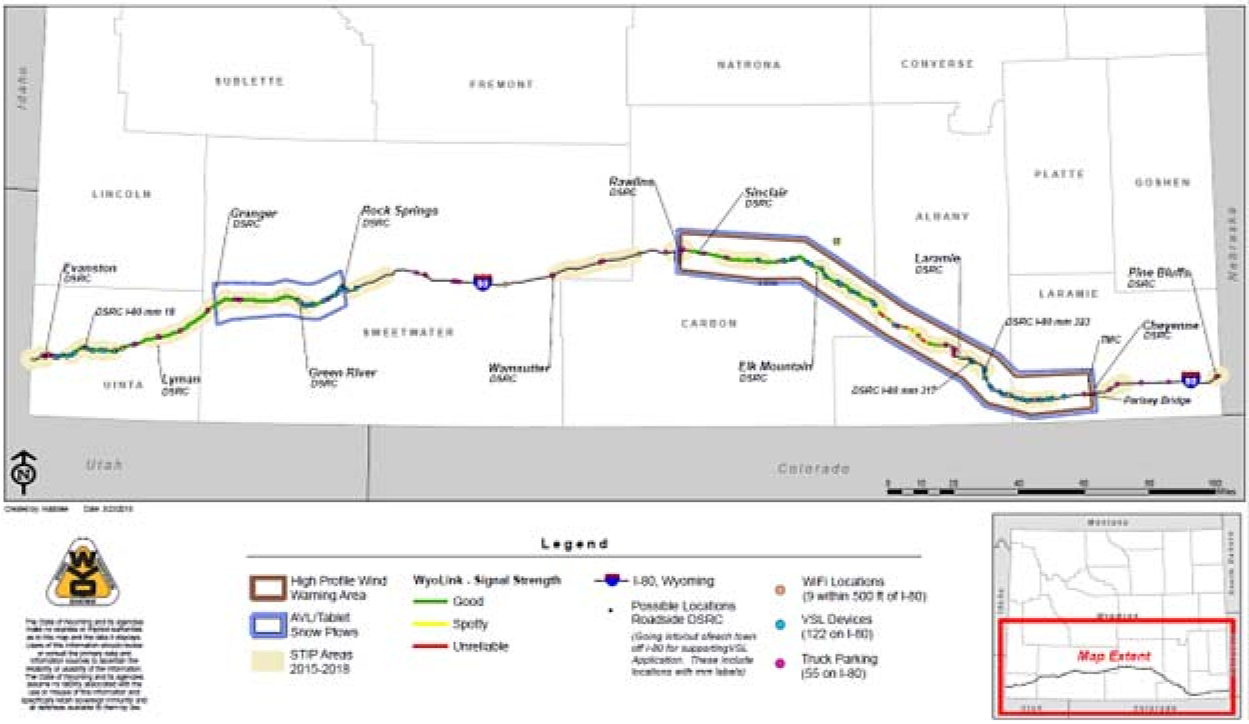


Image Source: (USDOT, 2018g).