Technology Transfer Case Study

Improving Work Zone Safety Technologies in Arizona and Kentucky

May 2020

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13. ABSTRACT

The United States Department of Transportation (USDOT) supports research development and technology transfer (T2) to promote safety, infrastructure, and innovation throughout the transportation system. This case study presents insights and knowledge from Federal Motor Carrier Safety Administration (FMCSA) grant recipients on Work Zone Safety (WZS), one of FMCSA’s national priorities. Roadway work zones pose numerous hazards to drivers, workers, and pedestrians, and work zones are particularly important to commercial motor vehicles (CMVs). In 2017, approximately 30% of fatal work zone crashes involved a large truck. To reduce these crashes, States and local agencies have explored a variety of WZS technologies and communications strategies. With support from FMCSA, these technologies are being piloted in Arizona and Kentucky in partnership with a wide array of stakeholders. This case study details the inputs, activities, and early outcomes associated with the pilot deployments of these technologies, and should be of interest to State and local agencies, potential technology adopters, and other operating administrations.

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Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	Mm
ft	feet	0.305	meters	M
yd	yards	0.914	meters	M
mi	miles	1.61	kilometers	Km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	Ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	G
lb	pounds	0.454	kilograms	Kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	G
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	Lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	In
m	meters	3.28	feet	Ft
m	meters	1.09	yards	Yd
km	kilometers	0.621	miles	Mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	Ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	Gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	Oz
kg	kilograms	2.202	pounds	Lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	Oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	Fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	Fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	Lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

Abbreviation	Term
ADOT	Arizona Department of Transportation
API	Application Programming Interface
CV	Connected Vehicle
CVISN	Commercial Vehicle Information Systems and Networks
CMV	Commercial Motor Vehicle
DSRC	Dedicated Short-Range Communication
ELD	Electronic Logging Device
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GPS	Global Positioning System
HP	High Priority
ITD	Innovative Technology Deployment
KTC	Kentucky Transportation Cabinet
MCDOT	Maricopa County Department of Transportation
MCSAP	Motor Carrier Safety Assistance Program
OA	Operating Administration
OBU	Onboard Unit
RSU	Roadside Unit
T2	Technology Transfer
TRB	Transportation Research Board
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
WZDx	Work Zone Data Exchange
WZS	Work Zone Safety

1. Introduction

Work Zone Safety (WZS) is a national priority for the Federal Motor Carrier Safety Administration (FMCSA). Roadway work zones pose numerous dangers to drivers, workers, and pedestrians. In 2017, there were 710 reported fatal work zone crashes, the highest total in ten years. Work Zone Safety is particularly important to commercial motor vehicles (CMVs), as 216 of the 710 fatal work zone crashes (30%) in 2017 involved a large truck.[1]

To reduce these crashes, States and local agencies have explored a variety of Work Zone Safety technologies and communications strategies. Arizona Department of Transportation (ADOT) and Maricopa County Department of Transportation (MCDOT) have tested smarter work zone concepts and currently use speed feedback signs, road sensors, cameras, and dynamic message signs to improve work zone safety. In Kentucky, the Office of Highway Safety conducts Work Zone Safety outreach through television, web, and radio.

The United States Department of Transportation (USDOT) supports research development and technology transfer (T2) to promote safety, infrastructure, and innovation throughout the transportation system. Federally funded research and development help move innovative technologies from Federal agencies to the marketplace. The operating administrations (OAs) of USDOT use a wide range of methods to support T2 and promote technology adoption, including pilot demonstrations, grants for early adopters, and the delivery of training courses. This case study presents insights and knowledge from the Federal Motor Carrier Safety Administration (FMCSA) that can inform the practices of other OAs, State and local agencies, and potential technology adopters.

This Technology Transfer Case Study focuses on commercial drivers only, given that the primary goal of the FMCSA is to improve commercial motor vehicle safety. Within this agency, the Innovative Technology Deployment (ITD) Program (formerly known as CVISN) is a key component of this critical safety work. Safety continues to be an overriding mission of the USDOT, with the National Highway Transportation Safety Administration (NHTSA) working on similar goals to improve safety for drivers using light vehicles.

While the report is focused on commercial drivers, the technologies presented are of course relevant to other Operating Administrations, like NHTSA, who aim to promote safety by having drivers slow down in work zones for their safety and that of transportation workers.

[1] National Work Zone Safety Information Clearinghouse. No date. "Work Zone Fatal Crashes and Fatalities." URL: https://www.workzonesafety.org/crash-information/work zone-fatal-crashes-fatalities/#national. Last accessed: April 7, 2020.

Figure 1. Attenuator Truck.
Source: Oregon Department of Transportation / CC BY 2.0.

1.1 Background

Despite the efforts of transportation agencies, work zones are still dangerous for those working in and traveling through them. The Commercial Motor Vehicle community recognizes how advanced technologies can improve Work Zone Safety. Specifically, invested parties want to increase Commercial Motor Vehicle drivers' access to real-time information on work zones, which can alert drivers in advance of upcoming work zones so they can pass through safely or select an alternate route. Figure 1, for example, shows an attenuator truck displaying the speed of oncoming traffic; such trucks aim to slow traffic approaching a work zone, thereby protecting workers and motorists.

To address safety needs, FMCSA has provided grant funding for States to improve safety awareness for Commercial Motor Vehicle drivers, bolster the efficiency and effectiveness of Commercial Motor Vehicle safety programs, and enhance data sharing.[2] The FAST Act, signed in 2015, consolidated FMCSA's grant programs into the Motor Carrier Safety Assistance Program (MCSAP) and the High Priority (HP) grant program. The High Priority grant program includes elements of the prior Commercial Vehicle

[2] Federal Motor Carrier Safety Administration. 2016. "The Commercial Vehicle Information Systems and Networks Program." URL:https://rosap.ntl.bts.gov/view/dot/31054.

Information Systems and Networks (CVISN) grant programs, and is now known as the Innovative Technology Deployment (ITD) grant program. The Arizona and Kentucky cases, detailed below, describe how teams comprised of State and local transportation agencies and Commercial Motor Vehicle entities are using Innovative Technology Deployment grant funds to create and test Work Zone Safety technologies.

This case study describes the Work Zone Safety technologies being piloted by Arizona and Kentucky. Rather than creating entirely new technology systems, both Arizona and Kentucky take advantage of existing, weigh station bypass technologies in developing their Work Zone Safety alert systems. The case study then maps, through a logic model, the technology transfer (T2) inputs and activities that Arizona and Kentucky undertook to develop and deploy their Work Zone Safety technologies. As Arizona and Kentucky are still in the early stages of technology deployment, this case study helps to establish a baseline for informing future performance measurement. The case study concludes by offering lessons and recommendations useful to future adopters of Work Zone Safety technologies.

2. Technology Narrative

The basic principle underlining Work Zone Safety technology is that commercial drivers need to be notified in advance of an upcoming work zone. Such notification can allow the commercial drivers to seek an alternate route or modify their driving (e.g., slowing down, shifting lanes) to ensure safe passage through the work zone. Since approximately 30% of fatal crashes in work zones involve a Commercial Motor Vehicle, there is interest from both the public and private sectors in improving Work Zone Safety.

FMCSA's Innovative Technology Deployment grant program allows State grantees to design and implement Work Zone Safety technologies that are tailored to each State's needs. States have discretion in selecting partners with which to develop and test Work Zone Safety technologies. ADOT worked closely with Maricopa County, the University of Arizona, a transportation software provider, and a private trucking company. The Kentucky Transportation Cabinet collaborated with the University of Kentucky and a second transportation software provider. While Arizona and Kentucky's Work Zone Safety deployments have broad similarities, there are some technical differences. These two States were chosen for this study due to their participation in the Innovative Technology Deployment grant program and their partnerships with local governments, universities, and the private sector. Additionally, both States were interested in using existing technology to improve safety conditions in work zones.

2.1 Arizona

ADOT's project is composed of two main parts: 1) short-range connected vehicle (CV) messaging to vehicles approaching work zones and 2) a work zone data stream that can broadcast messages using an application programming interface (API). Currently the connected vehicle and application programming interface parts of the project are separate components, but they may be integrated in the future. The project included pilot work zone locations along ADOT freeway sections and MCDOT arterial roadways.

2.1.1 Connected Vehicle Messaging

Vehicle-to-Infrastructure (V2I) connected vehicle technology enables dedicated short-range communication (DSRC) between onboard units (OBUs) in vehicles and roadside units (RSUs) or sensors on highway infrastructure. Onboard units can receive messages from roadside units and relay them to drivers through in-vehicle devices that display the messages. These in-vehicle devices can come in a variety of forms, including electronic logging devices, laptops, tablets, or mobile phones.[3]

In theory, roadside units near a work zone would be able to communicate with onboard units on trucks, alerting the driver of the upcoming work zone, speed changes, lane shifts, etc. However, ADOT has

[3] Altekar, Niraj; Das, Debashi; Head, Larry; et al. 2019. "In-Vehicle Work Zone Notification System for Connected Vehicles." Unpublished Paper.

encountered some limitations with using connected vehicle technologies for Work Zone Safety. As a result, ADOT prefers to wait for the connected vehicle market to mature further—namely for the market to achieve agreement on a spectrum standard for connected vehicle communications and for increased deployments of commercial vehicle-capable onboard units.[4] Once the market matures, ADOT in collaboration with MCDOT can better test for wide-scale deployment and adoption. Even when fully deployed, such connected vehicle technology would only be functional approximately 300 meters to one kilometer away from a work zone. This is not ideal for commercial drivers, who might need information several miles before the work zone to prepare and, if necessary, take an alternate route.

2.1.2 Application Programming Interface (API)

The second part of ADOT and MCDOT's project involves the creation of an application programming interface, which is a protocol that allows for real-time data exchange between users and a database. The application programming interface was developed in the new USDOT Work Zone Data Exchange (WZDx) Version 1.0 standard format. Such an application programming interface can offset some of the limitations of connected vehicle technology, allowing messages to be transmitted well before a commercial motor vehicle reaches a work zone. With an application programming interface ADOT and MCDOT send regularly updated work zone safety data to an open data source, making this data available to software developers and other interested parties. These parties can integrate this data into their mobile applications, broadcasting location-based messages to onboard units and in-vehicle devices. Data transmissions are activated through geofencing, which uses Global Positioning System (GPS) technology to create a virtual geographic boundary that enables software to trigger a response when a commercial motor vehicle enters a certain area.[5] Geofencing helps project leaders to customize the areas in which drivers receive specific messages.

For example, if ADOT and MCDOT want to send commercial motor vehicle drivers safety information two miles before a given work zone, it can push information through the application programming interface, which transmits coordinates defining a geofenced border two miles around the work zone. Any point on this border represents a point of entry. A third party with a mobile application can then use this geofenced border to generate and send information to commercial motor vehicle drivers. When commercial drivers with these apps cross a point of entry, data specific to that work zone will be activated and sent to the commercial driver. This flexibility allows ADOT and MCDOT to extend the Work Zone Safety information network beyond the short distances available with connected vehicle technology.

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[4] Interview with ADOT and MCDOT. August 2019.

[5] Drivewyze. 2018. "Transponder vs. Mobile Bypass Technology—Which One is Right for You?" URL: https://drivewyze.com/blog/trucking-tech/transponder-vs-mobile-bypass-technology-one-right/ Last Accessed: April 7, 2020.

2.2 Kentucky

Kentucky's Work Zone Safety technology resembles the application programming interface component of Arizona's project, but was developed in partnership with a different transportation software provider. Kentucky publishes work zone data in an open-source format, which becomes available to software vendors and developers who use the application programming interface to integrate the data into software to broadcast messages to in-vehicle devices. For truck drivers in Kentucky, work zone information is transmitted through a mobile application to in-vehicle devices like electronic logging devices, tablets, mobile devices, laptops, etc.[6] The work zone information is activated by geofencing technology, so that when commercial motor vehicles enter the virtual geographic area Kentucky designates for each work zone, users can receive messages through the apps on in-vehicle devices. Transmitted data also includes traffic congestion, active work zones, speed limits, and lane closures. Similar to the application programming interface component of Arizona's project, Kentucky's technology relies on software developers accessing the data to program the messages into their in-cab technology platforms.

Table 1 compares Kentucky and Arizona's WZS technology deployments.

Table 1. State Comparison of Technology Adoption

Description	Kentucky: API	Arizona: CV Messaging	Arizona: API
Connectivity	Geofencing	Dedicated Short Range Communication (DSCRC)	API
Range	Within 2 miles	Within DSRC range (up to 1km)	Within 2 miles
Adoption Status	Piloting	Awaiting market developments and further research	Piloting and expanding

[6] This particular app is from a public-private partnership suite of services that provides technologies related to bypassing weigh stations, paying tolls, and tracking fleet data.

3. Technology Transfer

Technology transfer (T2) refers to activities that are designed to ensure that technologies created or improved through research and development are widely adopted for use outside or within the research-producing organization.[7] To ensure that a technology transfer process can be applied beyond an initial pool of deployments, it is critical to catalog the various inputs and steps of that process. A logic model is a simple method for presenting key components of a technology transfer process.

3.1 Logic Model

A logic model illustrates the inputs (e.g., financial, legal, technical) that go into a particular technology, the activities associated with developing and deploying that technology, and the outputs and outcomes that may result from technology adoption. The primary inputs Kentucky and Arizona used to deploy their Work Zone Safety projects included Federal grant funding to States, Federal and State guidance, existing technologies, and information from stakeholders. Building on these inputs, Kentucky and Arizona created technologies to improve Work Zone Safety; deployed pilots to test these efforts; and gathered data on the technologies' effectiveness. To maximize the benefits of these technologies, the States are trying to increase information sharing among interested parties and wider technology adoption. Ultimately, such efforts could lead to a continuous exchange of work zone information, which will create safer and less congested work zones.

[7] Cuddy, Matthew, et al. 2016. "Building a Foundation for Effective Technology Transfer through Integration with the Research Process." URL: https://rosap.ntl.bts.gov/view/dot/12262 Last accessed: April 8, 2020.

Table 2. Logic Model.

Inputs	Activities	Outputs	Outcomes
• Grant programs (Innovative Technology Deployment) • FMCSA and State DOT support and guidance • Existing infrastructure and technologies • Agency, academic, and private partnerships • Priorities from leadership • Technical expertise	• Pilot deployments • Data gathering • Creation of work zone safety technologies • Stakeholder meetings • Creation of smartphone apps	• Adoption of work zone in-cab alert systems for CMV drivers • Work Safety Zone web/media campaigns • Changes in Work Safety Zone policies	• Continuous communication and peer exchange • More informed drivers • Enhanced safety around work zones • Reduced congestion around work zones • Increased up-to-date information and alerts available to drivers

3.2 Technology Transfer Inputs, Activities, and Expected Outputs

ADOT and the Kentucky Transportation Cabinet (KTC) sought input from a diverse group of commercial motor vehicle-involved entities to identify specific information that could be useful to truck drivers in work zones. KTC communicated with trucking leaders at national FMCSA meetings and partnered with the University of Kentucky to conduct a survey of priorities of involved parties. ADOT and MCDOT gathered data needs through meetings with automotive manufacturers, trucking associations, and a private-sector trucking partner, among others.[8] During in-person meetings with ADOT and MCDOT, the private-sector partner noted the need for very specific messages, including those providing situational awareness to drivers not familiar with local roads. The partner's safety officer also expressed interest in dynamic routing and other solutions to avoid trucks backed up at work zone queues.[9]

3.2.1 Agency Partnerships

ADOT and KTC partnered with other transportation agencies to help develop and deploy their Work Zone Safety technologies. Recently, FMCSA sponsored, in partnership with ADOT and MCDOT, a

[8] For further discussion of seeking input for technology transfer, see also: Epstein, Alexander and Santiago Navarro. 2018. "Developing and Executing Your Technology Transfer Plan: A 10-Point Checklist." URL: https://rosap.ntl.bts.gov/view/dot/36733 Last Accessed: April 7, 2020.
[9] Interview with ADOT and MCDOT. August 2019.

demonstration on connected vehicles in work zones in Arizona. Together, the three agencies worked to fine-tune ADOT's technology with the goal of improving safety and traffic conditions within work zones.[10] Further, in collaboration with the Federal Highway Administration (FHWA), Maricopa County held a work zone data peer exchange in July 2019. This peer exchange brought together federal, state, and county agencies alongside universities and the private sector to share information on their respective Work Zone Safety initiatives as well as ways to promote deployment and adoption.[11]

3.2.2 Academic Partnerships: University of Kentucky and University of Arizona

ADOT and KTC collaborated with academic institutions to develop and test their technologies. Kentucky partnered with members of the University of Kentucky Transportation Research Center to deploy the Work Zone Safety technology pilot. The University of Kentucky's Transportation Research Center met with members of the commercial motor vehicle community and government agencies to develop a survey on in-cab data needs.[12] Over 1,500 respondents in the trucking community completed the survey, and work zone information was identified as a top area of interest. In particular, drivers wanted to be warned of work zones ahead of time so they could avoid waiting in queues. Additionally, if drivers could not avoid a work zone, they still wanted to be alerted for safety reasons, as construction workers might be in the area. These survey results helped tailor Kentucky's work zone technology project to meet the needs of the public and technology adopters.

ADOT and Maricopa County partnered with the University of Arizona to develop technology for their Work Zone Safety project. The University of Arizona was included in early vision meetings to develop customized technology to integrate existing in-cab messaging with various safety alerts relevant to commercial motor vehicles.[13, 14]

3.2.3 Private Sector Partnerships: National Freight and Software Companies

In addition to establishing agency and academic partnerships to develop their technologies, Arizona and Kentucky cultivated private-sector partnerships to test Work Zone Safety messages. ADOT, MCDOT, and KTC's data stream/application programming interface technology deployments required in-cab equipment to be specifically set up to receive and display the States' work zone data. To test the

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[10] Interview with ADOT and MCDOT. September 2019.

[11] Federal Highway Administration. No date. "The Work Zone Data Initiative: Smarter Work Zones and Work Zone Activity Data. Peer Exchange and Demonstration Site Visit – Meeting Summary." URL: https://collaboration.fhwa.dot.gov/wzmp/Arizona%20July%20910%202019/Arizona%20PX%20Meeting%20Summary%20FINAL.pdf. Last accessed: April 7, 2020.

[12] These stakeholder groups consisted of Division of Motor Carriers, Office of Information Technology, Kentucky State Police, FMCSA Kentucky Office, and Kentucky Trucking Association.

[13] Federal Motor Carrier Safety Administration. 2018. "Federal Motor Carrier Safety Administration: Innovative Technology Deployment of Work Zone Safety Systems." URL: https://www.workzonesafety.org/files/documents/news_events/wz_conference_2018/day2_track2_large_trucks-Kelly.pdf. Last accessed: April 7, 2020.

[14] Interview with ADOT and MCDOT. August 2019.

function and potential of the data stream/application programming interface technology, ADOT worked with a national freight company based in Phoenix and a transportation software company, which specializes in weigh station bypasses. This software company leverages application programming interfaces to construct geofenced areas, facilitate weigh station bypasses, and inform drivers of important safety-related messages. The freight company that partnered with ADOT uses this technology in all of its vehicles.[15] Kentucky partnered with a different transportation-software company, which has also developed geofencing-based mobile applications to perform weigh station bypassing and send safety-related messages to commercial motor vehicle drivers.[16]

Arizona's software provider incorporated API data into its application, so truck drivers with that provider's app can be alerted when approaching a work zone. Similarly, Kentucky's software provider integrated information into its mobile application, so CMV drivers in Kentucky with that app would be notified when approaching one of the test work zones. These partnerships have sizeable implications for scaling up: in addition to their own outreach efforts, Arizona and Kentucky can leverage these apps' large customer bases to accelerate technology adoption.

3.2.4 Piloting: Helping to Work Through Challenges

Arizona and Kentucky both used pilots to test their in-cab notification systems in real-life work zones. Such piloting has helped the States work through any bugs in their technologies and discover challenges to using their products in a real-life setting. For example, by running a pilot in partnership with a large freight company, which provided ten testing trucks, Arizona learned that it is difficult to install RSU equipment in work zones because sometimes there are no poles to mount the equipment. Additionally, there can be electricity difficulties. To solve these problems, Arizona had to develop an enclosure prototype with a processor that needed to be protected from the heat. [17]

Kentucky, along with members of the University of Kentucky Transportation Research Center, drove pilot vehicles around construction zones to see if the app was properly notifying them of construction data.[18] Pilots helped Arizona and Kentucky optimize and adjust their advanced technologies to ensure that they would work in a scaled-up, real world setting. Additionally, Arizona and Kentucky both used the pilots to collect data, which can help to develop performance measures for deployment.

3.2.5 Technology Adoptions

As of this writing, Arizona and Kentucky are still completing their Work Zone Safety pilot projects and are focusing adoption outreach efforts to immediate partners. However, after finishing its pilot, Kentucky will start outreach efforts via its website to notify the public about its Work Zone Safety

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[15] Interview with ADOT and MCDOT. August 2019.
[16] Interview with Kentucky Transportation Cabinet (KTC). August 2019.
[17] Interview with ADOT and MCDOT. August 2019.
[18] Interview with KTC. August 2019.

notification system. Kentucky is also going to encourage its software partner to advertise the technology to its customers and work with state partners to do the same with Kentucky motor carriers. Arizona has already conducted some outreach efforts to increase adoption, including presentations to key parties, a paper submitted to the Transportation Research Board (TRB) on Work Zone Safety research, and a number of peer-exchange presentations with State governments and other organizations. Since Kentucky and Arizona are both using open source data, a major key to advancing adoption of their Work Zone Safety technologies is to increase product awareness.

3.2.6 Improvements in Safety Outcomes and Fleet Time Savings

These Work Zone Safety technologies are expected to have significant benefits to Arizona (both on freeway and arterial roads) and Kentucky, including safer work zones, better traffic management, and more effective communication of highway conditions with motor carriers. While definitions of a "safe work zone" differ, many programs addressing this issue note the importance of reducing speed, providing drivers enough notice, and improving driver alertness.[19, 20] Additionally, the in-cab notifications will provide numerous benefits to the commercial motor vehicle industry, including increased information in helping drivers navigate through work zones safely or choose alternate routes.[21] These outcomes can help reduce the high fatality and accident rates in work zones, as well as improve congestion and vehicle travel times in and around work zones. To date, there is insufficient data to measure the safety and operational effects of Arizona and Kentucky's Work Zone Safety programs, but, as adoption of these technologies increases, it will be easier to evaluate the effects of these technologies against a baseline or comparison case.

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[19] National Work Zone Safety Information Clearinghouse. No date. "Strategies to Enhance Large-Truck Safety in Work Zones." URL: https://www.workzonesafety.org/training/strategies-to-enhance-large-truck-safety-in-work zones/. Last accessed: April 7, 2020.

[20] Federal Motor Carrier Safety Administration. 2019. "Work Zone Safety Tips." URL: https://www.fmcsa.dot.gov/ourroads/work zones-safety-tips. Last accessed: April 7, 2020.

[21] Arizona Department of Transportation. No date. "Arizona Expanded CVISN Program Plan / Top-Level Design." Unpublished document.

4. Lessons and Recommendations

The experiences of the teams from Arizona and Kentucky in developing and transferring work zone technologies for commercial motor vehicles provide several lessons that could benefit other States developing and deploying similar applications. Some of the lessons come from the challenges faced by the teams, while other lessons recognize actions that advanced the development and deployment processes.

4.1 Lessons Learned

The experiences of Arizona and Kentucky in deploying their Work Zone Safety pilots highlighted the following lessons: it is critical to obtain quality data on what technology users deem necessary; there are existing technologies that can be adapted, reducing development costs; and agencies might face technical problems beyond their abilities to address.

4.1.1 Engaging User Communities to Identify Needs

The research conducted by Kentucky and Arizona on in-cab data needs—trucking community survey, vision meetings, and interviews—identified work zone information that would be most helpful to motor carrier operators. Work zone data streams and messages were customized for the pilots with these needs in mind. Highlighting the value of customized work zone information could encourage software vendors and developers to use the work zone data and incorporate the messages into their in-cab systems.

In addition to identifying technologies to improve Work Zone Safety, Kentucky's and Arizona's partnerships with major trucking software companies will make it easier for future users to adopt Work Zone Safety technologies. Since the apps that Kentucky and Arizona piloted are already widely accepted and used (for weigh station bypasses), it will be straightforward for fleets and drivers to adopt Work Zone Safety notifications that are seamlessly integrated into those apps, compared to creating an entirely new technology infrastructure or installing a separate app.[22]

4.1.2 Adapting Existing Technologies

In developing their work zone technology pilots, both Kentucky and Arizona partnered with technology companies offering in-cab applications and software, currently used for weigh station bypass services. Kentucky turned an existing relationship with a software provider into a data-sharing partnership. Similarly, Arizona took advantage of its partnership with a major freight company to bring a software partner on board for their Work Zone Safety research.

[22] For further discussion on understanding adopters' needs, see Cuddy et al. 2016.

The participation of major software partners in the work zone technology pilots allowed Kentucky and Arizona to develop a work zone messaging system at a relatively low cost. There was no need to acquire new equipment or software for the project, as these were already in place for users of these weigh station bypass apps. This arrangement allowed the teams to focus on developing the data stream, along with an application programming interface, so the work zone data could be placed on an open data source. The model of developing open source data feeds to be used with existing technology could work well for other State or local agencies who seek to share data. The partnerships reduced the burden of developing and testing the Work Zone Safety technology. Ultimately, these partnerships can provide a large number of in-cab technology users with immediate access to the Work Zone Safety data, expediting technology transfer.

4.1.3 Technology Roadblocks

This case study describes long-range messages made available to software vendors through an open source data stream. Although the Arizona team is developing a short-range connected vehicle system that provides real-time work zone messages based on a vehicle's speed and position (using Dedicated Short Range Communication), the team has not yet been able to fully test the system. Challenges to installing and using message transmission equipment (e.g., roadside units) have delayed testing. Additionally, the mapping software needed to fully implement the system is still in the early stages of testing. Arizona interviewees noted that, "the CV piece will take a little while longer, because the industry needs to mature."[23] Other teams looking to deploy work zone technologies can benefit from Arizona's experiences to understand the challenges to developing, installing, and using connected vehicle technology.

4.2 Recommendations

To facilitate future adoption of Work Zone Safety technologies, the case study team recommends that FMCSA develop a forum for sharing information from pilot deployments and that early technology adopters conduct program evaluations to preserve results and lessons learned.

4.2.1 Create Specific Fora for Sharing Information

Although the teams noted support from FMCSA for funding pilot projects and demonstrations, neither described a formal system within the Innovative Technology Deployment program for in-depth information sharing. Both Kentucky and Arizona take part in monthly Innovative Technology Deployment program manager calls, but interviewees described these calls as primarily for project updates, leaving less time for detailed information sharing. The program portal was also an underused

[23] Interview with ADOT and MCDOT. August 2019.

resource. FMCSA has indicated future support for information sharing and promoting the Innovative Technology Deployment portal.[24]

To support teams conducting Work Zone Safety pilots, we recommend that the ITD program create a specific opportunity for grantees to share information, methods, progress, and lessons learned related to work zone safety technologies. Possible vehicles for sharing could include a peer exchange, scheduled presentations at meetings or via webinar, or virtual work groups for grantees undertaking similar projects. Both teams have used existing relationships with other State agencies to share and gather information about work zone projects. Additionally, Arizona is presenting work zone safety project information through ADOT/MCDOT presentations to key parties, FHWA peer exchanges, Transportation Research Board, and other fora.

4.2.2 Conduct Program Evaluations

Neither State described a formal evaluation plan for the deployment of Work Zone Safety technologies. However, evaluation of key questions and the gathering of baseline and performance data can be highly informative for future technology adopters. In the future, grantees should consider incorporating program evaluation into technology deployments to help record important successes and lessons. Grantees' academic partners would be adept at performing such evaluations.

[24] Communication with FMCSA. November 2019.

5. Conclusion

With support from FMCSA's Innovative Technology Deployment grant program, Arizona and Kentucky collaborated with academia, the private sector, and other public and private entities to identify commercial motor vehicle needs and develop Work Zone Safety technology. Both States worked with existing transportation-software providers and their apps to develop application programming interfaces that would work with these widely accepted apps. By assessing the commercial motor vehicle community's needs early and collaborating with existing software providers, both States saved money in technology development while also maximizing potential technology adoption. As more commercial drivers adopt these technologies, we recommend that Arizona and Kentucky evaluate the safety and operational effects of Work Zone Safety technologies.

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Appendix A: Technology Transfer Case Study Interview Guide

Script: As mentioned in our emails, we work with the US Department of Transportation's Volpe Center, and we are collaborating with FMCSA and the US DOT Office of the Secretary to identify and research good practices in technology transfer. In particular, we are looking at how Work Zone Safety technologies funded under FMCSA's Innovative Technology Development (ITD) program were researched, developed, and deployed. The team's research will ultimately produce a case study, which will be publicly published and serve as a technology-transfer example for other US DOT modes and interested stakeholders.

Thank you again for your time today. (Name) here will be assisting me today by typing your responses as we talk. We know that you have a busy schedule, so let's go ahead and get started.

INTRODUCTION

1. Would you please describe the Work Zone Safety technology that your agency has developed with the ITD grant funds?
    a. (Probe) How does it work?
    b. (Probe) Who would use it?
    c. (Probe) What equipment is required for use of the technology? Does it require purchase, installation, training, etc.?

2. We understand that you are currently piloting Work Zone Safety technology. Is that correct, or are you deploying the technology at a larger scale? Would you tell us more about this pilot?
    a. How did you choose your particular vendor?
    b. Who is participating in this pilot?
        i. How were these participants chosen?
    c. Does this particular pilot have performance measures, or is that not the case?
    d. What kind of data are you collecting in this pilot?

MARKET NEEDS AND TECH DEVELOPMENT

To help other agencies who will go through the process of understanding the market and developing technologies for Work Zone Safety, we'd like to talk about some aspects of market research and technology development.

3. Prior to the ITD program, which technologies or strategies did your agency use to improve work zone safety?
    a. Were these technologies or strategies effective?

4. Has your State passed any recent laws, policies, or regulations that might impact Work Zone Safety (e.g., Safety Vest Law)?

5. How did your agency determine that there was a need for Work Zone Safety technology?
   a. (Probe) Did your agency assess motor carriers' existing technological capacities with respect to Work Zone Safety, or was that not necessary?
      i. (if yes) How did you do that?

6. What groups were involved in the *development* of the technology?
   a. (Probe) Public sector partners, Private sector partners (e.g., technology vendors, trucking community), academia
   b. Were these groups involved throughout technology development, or only at certain stages?
   c. Did your agency track feedback from these groups, or was that not the case?

7. Are there any other technologies on the market that are similar to your WZS project?
   a. How does your WZS project differ from these technologies?

8. Would you please describe how the technology was tested?
   a. (Probe) Were end users involved?
   b. (Probe) Did you provide trainings, webinars, or other activities to assist with technology testing?

TECHNOLOGY TRANSFER/DEPLOYMENT

We'd now like to ask your questions about technology transfer—that is, the process by which your agency is encouraging the *awareness* and *adoption* of work zone safety technology. Technology transfer is also referred to as tech transfer or T2.

9. Did your agency develop a plan for transferring the technology to users, or was that not the case?
   a. (Probe) Would you tell us about this plan?

10. Depending on a given technology, there are many stakeholders that can be engaged during technology transfer. Some of these stakeholders include drivers; fleet managers; business owners; trade associations; and so forth. Which stakeholders did you engage to encourage awareness and adoption of this technology?
    a. What activities did your agency undertake to encourage awareness and adoption of this technology?
       i. (Probe) Informational Website/Emails/Newsletter
       ii. (Probe) Trainings, Webinars, Panels, Peer exchanges, etc.
       iii. (Probe) Demonstrations
    b. Did your agency track feedback or communications from these stakeholders?
       i. What kind of feedback did you receive from stakeholders as you encouraged awareness of this technology?

11. What were your agency's goals in terms of technology awareness and adoption?

    a. Did your agency create an evaluation plan or develop performance measures?
    b. (Probe) Would you tell us a bit more about this evaluation plan or performance measures?

12. Did your agency recruit people to champion the technology for adoption, such as agency staff or industry representatives?

13. Would you say that your agency came across any barriers to adoption, or was that not the case?

14. How would you describe stakeholder feedback so far on this technology?
    a. (Probe) Users, firms, associations, work crews, law enforcement, etc.

15. Roughly how many drivers have adopted this technology?
    a. What is your ultimate goal for technology adoption?

16. Would you say that the technology has changed user behavior, or is it too early to tell?
    a. (Probe if applicable) Would you say that the technology has improved safety outcomes, or is it too early to tell?

17. Do you plan to expand the project to other users in the future? If so, to whom?
    a. Do you plan to make modifications to the project and/or tech in the future? If so, how?

ROLE OF FMCSA

We'd now like to ask a few questions related to the role of FMCSA in your State's development and deployment of Work Zone Safety technology.

18. How did FMCSA support the deployment of the technology?
    a. (Probe) Besides money?
    b. Beyond FMCSA, were there other sources of support for this technology?

19. We understand that roughly each month, FMCSA hosts an ITD program managers' call. Would you say that those calls have been useful, or is that not the case?
    a. (Probe) Do States share their experiences with regard to transferring new technologies?
    b. (Probe) Have you found helpful advice from that call with respect to Work Zone Safety technology?
    c. (Probe) Have you had a chance to coordinate with other states regarding Work Zone Safety technology adoption, or is that not the case?

20. We understand that FMCSA also maintains a Portal for ITD projects. Would you say that that Portal has been useful for your Work Zone Safety project, or is that not the case?

21. We understand that *FHWA* has its own Work Zone Safety technology program. Has your State coordinated with FHWA's program, or is that not the case?

a. (Probe) Would you please tell us more about this coordination with FHWA?

22. What were challenges you faced in developing and deploying the Work Zone safety project?

This brings our interview to a close. Before we leave, is there anything else you would like to add? Is there anyone else at your State with whom we should speak?

Thank you for your time today. If we have additional questions, is it alright if we get back in touch with you again? Have a nice day.

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