Paving the Way for Autonomous and Connected Vehicle Technologies in the Motor Carrier Industry

Final Report
May 2018

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16. Abstract

This study provides potential safety considerations and infrastructure needs that will support the mass adoption of autonomous vehicle (AV) and connected vehicle (CV) technologies in the motor carrier industry. Using large truck crash data from 2013 through 2015 obtained from the Missouri State Highway Patrol, chi-square automatic interaction detection (CHAID) decision trees were estimated to examine the effect of AV and CV technologies on motor carrier crash severity. Results suggest that the greatest contributory predictors of crash severity outcomes are driving too fast for conditions, distracted/inattentive driving, overcorrecting, and driving under the influence of alcohol. If these circumstances are altered by AV and CV technologies, it is suggested that between 117 and 193 severe crashes involving large trucks could be prevented annually in Missouri alone.

To render such safety benefits, key vehicle needs include autonomously controlling acceleration and steering, monitoring of the environment, and responding to dynamic driving environments without the need for human intervention. Importantly, the safe operations of a system that can perform such AV and CV tasks require readable lane markings, traffic signals and signs, managed or dedicated lane usage, and dedicated refueling and/or recharging facilities.

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PAVING THE WAY FOR AUTONOMOUS AND CONNECTED VEHICLE TECHNOLOGIES IN THE MOTOR CARRIER INDUSTRY

Final Report
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Principal Investigators
Ray A. Mundy, John Barriger III Professor for Transportation Studies and Director
Center for Transportation Studies, University of Missouri-St. Louis

Jill M. Bernard Bracy, Assistant Teaching Professor, Marketing
Assistant Director for Program Development, Center for Transportation Studies
College of Business, University of Missouri-St. Louis

Research Assistant
Ken Bao

Authors
Jill M. Bernard Bracy, Ken Bao, and Ray A. Mundy

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A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

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INTRODUCTION

Potential financial gains and safety enhancements provide incentives for mass adoption of autonomous vehicle (AV) and connected vehicle (CV) technologies in the motor carrier industry, and, as a result, assumptions are made that motor carriers will be one of the first adopters of automated driving capabilities. AV technology can replace human drivers with a computation-based decision-making process for a varying array of driving tasks, while CV technologies focus on vehicle-to-vehicle (V2V) communications by synchronizing the movements of nearby vehicles. Truck platooning, one of the more relevant CV applications for trucking operations, describes at least two trucks that drive in a synchronized fashion, where the lead vehicle dictates the actions of the following vehicle(s).

The Society of Automotive Engineers (SAE) defines levels of automation based on the extent to which driving tasks are delegated to the vehicle (SAE International 2016), as presented in Table 1.

Table 1. SAE defined levels (2016)

SAE Level	Name	Definition
0	No Automation	Full-time performance by the human driver in all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
1	Driver Assistance	Strictly driver-augmenting. Consists of the system performing very specific tasks under specific driving modes with the expectation that the human driver performs all remaining tasks.
2	Partial Automation	Same as level 1, except there can be multiple driver assistance systems (also only under specific driving modes).
3	Conditional Automation	The automated driving systems (ADS) can perform all aspects of the dynamic driving task under certain driving modes with the expectation that the human driver will respond when requested to intervene.
4	High Automation	Same as level 3, but the system does not require human intervention.
5	Full Automation	Full-time performance by an ADS for all aspects of the dynamic driving task. Steering wheel is optional.

Benefits rendered from such technologies include combating driver shortages, retaining drivers, improving drivers' health and wellness, reducing driver fatigue while adhering to the hours of service regulations, mitigating driver distraction, lowering fuel consumption, and, importantly, diminishing unsafe driving (Bhoopalam et al. 2018, Short and Murry 2016). Unsafe driving behaviors for motor carrier drivers include speeding, reckless driving, improper lane changes, following too closely, improper passing, driving too fast for conditions, failing to yield, and distracted driving (Bernard and Mondy 2016, Short and Murry 2016). Though unsafe driving will not disappear, it is probable that the number of unsafe driving events will decline as drivers shift to autonomous driving (Short and Murry 2016). To the extent that the diffusion of AVs and CVs will affect the number of unsafe driving events, transportation policymakers have a responsibility to facilitate the adoption of such technologies. This study focuses on infrastructure requirements as a primary policy concern.

REQUIRED INFRASTRUCTURE

The vision for the motor carrier industry is characterized by the dominance of highly autonomous trucks with a decentralized platooning capability. For this to manifest into reality, current infrastructure, especially for Interstate roadways, must evolve with the demands from such technological advances. This study provides a comprehensive look at the infrastructure needs for AV and CV trucks to operate safely in a mixed vehicle environment, in which vehicles range from fully manual to fully autonomous.

AV Technology

An SAE level 4 system is one that can autonomously control acceleration, steering, monitoring of the environment, and acting correctly in a dynamic setting (National Highway Traffic Safety Administration 2016). The highest level of automation, SAE level 5, is achieved when all the capabilities of an SAE level 4 system can be safely carried over to all driving situations, such as merging onto a freeway, traffic jams, and construction detours. The ability for a system to correctly execute acceleration commands relies entirely on the attributes of the system and is not dependent on external characteristics, such as infrastructure quality. This technology has existed for some time, and almost all modern passenger cars have cruise control capabilities. However, cruise control settings still require users to input a speed to maintain, and therefore the task is automated as opposed to autonomous. The difference between the two terms is that an automated system is one that can only act under the confines of its pre-specified programs, whereas an autonomous system is characterized by its ability of self-governance and functions at a higher level than automation (Fitzpatrick et al. 2016).

Achieving autonomous rather than automated acceleration requires that a system be able to ascertain speed limit information independently from the driver, which will require vehicle-to-infrastructure (V2I) communication. For the purposes of autonomous acceleration, the necessary level of V2I-capable infrastructure investment will likely be modest. It is possible that a transmitter attachment is the only necessity for most situations, and the attachment would be able to convey speed limit postings to self-driving vehicles as they appear on the road.

In theory, there are alternatives that can avoid the need for V2I infrastructure. For instance, a system retains the speed limit posting for all legs of a certain route or geographical region. However, a problem arises when speed limits change and are not immediately integrated into the operating software. Another possible solution is to develop advanced visual detection systems so that a self-driving system can observe the speed limit posting independently. However, any such detection system would likely be less reliable without improved infrastructure, especially under poor meteorological conditions. Fortunately, it may be possible to combine both methods, which would bypass the flaws of using only one of the two.

To implement autonomous steering, a system must be able to reliably detect lane markings and possess independent navigation capabilities. For operational safety, it is likely that lane markings for many current roadways need to be improved.

SAE level 3 or higher also requires that the automated system perform the task of monitoring the entire driving environment. This goes beyond simply monitoring the driving lane and includes tasks such as monitoring traffic, traffic signals, and other roadway conditions, which may require improved traffic signs and signals. Whether the current traffic signs and signals require improvement depends largely upon the development of sensory technology. Although most of these functions do not require major changes in infrastructure, efficiency gains could result from such improvements. For instance, it would be beneficial to design the driving environment around the autonomous system as opposed to designing the system around the driving environment. This can be achieved through dedicated autonomous lanes for freight or passenger vehicles or both. If the driving environment is simplified and/or more predictable, then relying upon the system would be much safer and more efficient.

A system reaches SAE level 4 if it does not require a human driver for "fallback" operations. Although the definition of a fallback operation is unclear and likely inconsistent among proprietary technologies, the concept itself is constant. If a system is not confident about how to proceed in a given situation or if it fails to act completely, it will request driver intervention. Once a system can overcome this dependency, then the infrastructure required to support level 4 vehicles would likely be minimal.

Similarly, the advancement from SAE level 4 to 5 requires that all previously mentioned tasks be applicable in all dynamic driving situations, such as poor weather or construction, and implies that no additional changes in infrastructure are necessary. However, since SAE level 5 guarantees that driverless operations are safe, whereas anything below level 5 does not, additional infrastructural concerns arise. In the case of the motor carrier industry, where benefits from AV technology are the highest among long haul operations, infrastructure investments are needed to address the refueling demands of self-driving freight trucks.

Outside of dense urban areas, however, it is unclear whether it is necessary to develop or update existing gas stations to accommodate autonomous freight trucks. For example, if a freight truck with two 150-gallon diesel tanks and an average of 7 miles per gallon can drive up to 2,100 miles before needing to refuel, then the route would simply need to include a leg with a nearby refueling station. Therefore, it may not be necessary for refueling points outside of cities. However, if the internal combustible engine becomes obsolete, then recharging stations designed for autonomous vehicles would be required. Alternatively, inductive charging technology could be incorporated onto the road itself or solar charging equipment would eliminate the need for autonomous vehicles to stop and recharge.

Platooning Technology

Platooning involves at least two trucks driving in tandem, one in front of the other and maintaining a specified distance. This maneuver is facilitated by CV technology, where the lead truck dictates the operations of the following trucks. In this way, the platooning trucks work synergistically to affect the air flow such that all trucks save on fuel. This type of technology is most useful for long haul transportation and SAE levels 4 or lower, in which a driver may still be required to remain present in the lead vehicle but not the following ones.

In practice, platoons can resemble trains in their length and the distance apart from one another, which can present different challenges for the nation's highway infrastructure. A primary issue could arise if such "road-trains" prevent manually operated passenger vehicles from moving about lanes. Highway merging and exiting maneuvers would likely be made much more difficult in the presence of large freight truck platoons cruising in the right lane.

One possible solution would be to have dedicated highway lanes and independent ramps for platoons and AVs. The left lane highway ramps could be limited to trucks, whereas the dedicated lane would be for all AVs and truck platoons. The dedicated lane would ideally be the left lane, which would open the right lane for traffic to freely merge and exit. Exiting a highway would be much safer, since one could cruise in the right lane without concern for crossing a gap among the platoons. Hopefully, an autonomous system will be capable of safely operating around both AV/CV and manual traffic before it is legally allowed to operate on roads, but even then there are concerns about how human drivers will behave around AVs/CVs. It could be the case that driving alongside AVs/CVs would create pressure and anxiety among human drivers, especially in the presence of long platoons of trucks. Additionally, it may not be easy to formulate rules and standards for mixed traffic lanes as well as for educating drivers about how to properly act in mixed traffic situations. Therefore, a dedicated lane for AV/CV traffic could have enormous safety improvements, at least at the outset.

The infrastructure requirements proposed above could pose an insurmountable fiscal burden on the relevant governing agencies. However, the potential safety benefits for the motor carrier industry induced by the implementation of AV and CV technologies will hopefully be a justification for investment.

Data

To consider the potential safety benefits of employing AV and CV technologies, this study analyzed large truck crash data from 2013 through 2015 obtained from the Missouri State Highway Patrol. Personal, vehicle, and crash data were retrieved from the Missouri Statewide Traffic Accident Records System (STARS) database. The combined datasets resulted in 1,083,150 records with 237 variables. Motor carriers (defined here as a single-unit truck with two or more axles, truck tractors, and other heavy trucks) were involved in 6.8% of the total crashes in Missouri from 2013 to 2015 (28,754 out of the 425,374 crashes), and motor carrier drivers were found to have contributed to 15,338 of these crash occurrences.

After a crash occurs, the circumstances contributing to the crash as determined by the investigating officer is recorded. Table 2 presents the frequency of occurrence for each contributing circumstance in which the motor carrier driver was found to have contributed to the cause of the crash.

Table 2. Frequency of circumstance contributing to a large truck crash

Contributing Circumstance	Counts	Percentage of Total
Improper Lane Use / Change	2,877	17.74%
Distracted / Inattentive	1,726	10.64%
Too Fast for Conditions	1,699	10.48%
Improper Turn	1,327	8.18%
Failed to Yield	1,243	7.66%
Following Too Close	1,137	7.01%
Other	1,082	6.67%
Vehicle Defects	758	4.67%
Improper Backing	629	3.88%
Vision Obstructed	430	2.65%
Animal in Roadway	414	2.55%
Failed to Secure Load	383	2.36%
Improper Passing	360	2.22%
Overcorrected	326	2.01%
Object in Roadway	270	1.66%
Driver Fatigue / Asleep	263	1.62%
Violation of Signal/Sign	256	1.58%
Wrong Side (Not Passing)	250	1.54%
Alcohol	175	1.08%
Physical Impairment	132	0.81%
Improperly Stopped on Roadway	121	0.75%
Speed - Exceed Limit	109	0.67%
Improperly Parked	78	0.48%
Drugs	56	0.35%
Improper Towing / Pushing	32	0.20%
Improper Signal	30	0.18%
Wrong Side (One-Way)	26	0.16%
Improper Start from Park	19	0.12%
Failed to Use Lights	6	0.04%
Improper Riding	3	0.02%
Failed to Dim Lights	0	0.00%
Total	**16,217***	**100.00%**

* The sum of the frequency of contributing circumstance can exceed the number of cases, since multiple citations of contributing circumstance may be present in a given crash.

METHODOLOGY

Decision trees were used as the methodological approach to examine the effect of AV and CV technologies on motor carrier crash severity. Decision trees have several advantages over other models: nonlinear relationships between variables do not affect performance, the data partitioning yields insights into input / output relationships, each path of the decision tree contains an estimated risk factor, missing values are accommodated automatically, and the output is simple to understand and interpret (Bernard Bracy 2017). One type of decision tree, chi-square automatic interaction detection (CHAID), is built by applying decision rules sequentially that split a larger heterogeneous population into smaller, more homogeneous subsets based on the most predictive explanatory factor (Eustace et al. 2016). Subset purity is measured and evaluated to determine the best split for the subset (Mingers 1989), and factors deemed statistically homogenous are combined (Trnka 2010). Splitting continues for each node until no more splits are possible, and the CHAID algorithm automatically prunes the decision tree to avoid overfitting (Bayam et al. 2005).

The CHAID methodology used here employs the algorithm proposed by Kass (1980), and the estimation of the model considers the explanatory variables identified in Table 2. The Pearson measure was used as the chi-square measure to test for independence for categorical targets, and the significance level for both splitting and merging was set to 0.05. The CHAID algorithm nodal splitting criteria was set to a minimum absolute value of 100 records in a parent branch and a minimum of 50 records in a child branch, and the maximum tree depth was set to 15 branches. The results from the CHAID decision tree were used to determine the reduction in severe crashes by considering circumstances altered by AV and CV technologies.

Using the results from the CHAID decision tree, historical outcomes were examined to determine upper and lower bounds on the changes in the number of drivers involved in fatal, injury, or property damage only crashes if selected contributory circumstances are individually eliminated because of AV and CV technologies. Bounds for changes in the annual number of drivers involved in each level of severity outcomes were calculated by (1) removing the contributing circumstance for each driver and assuming the crash still occurs with severity outcome probabilities now determined by the outcome probabilities of the complementary node (a lower bound) and (2) removing the contributing circumstance and assuming that the driver is not involved in a crash at all (an upper bound) (Bernard Bracy 2017). The analysis provides a context for understanding the relative reduction in risk associated with reducing the frequency of circumstances likely to contribute to different crash severity outcomes, which can provide justification for the necessary AV and CV infrastructural modifications.

RESULTS AND DISCUSSION

Between 2013 through 2015, motor carriers (with a driver present) were involved in 28,925 crashes in Missouri, and motor carrier drivers were found to have contributed to 15,338 of these crashes, resulting in 105 fatal and 1,596 injury outcomes. The CHAID decision tree results suggest that the greatest contributory predictors of severity outcomes for crashes in which a motor carrier driver was found to have contributed are driving too fast for conditions, distracted/inattentive driving, overcorrecting, and driving under the influence of alcohol, as presented in Figure 1.

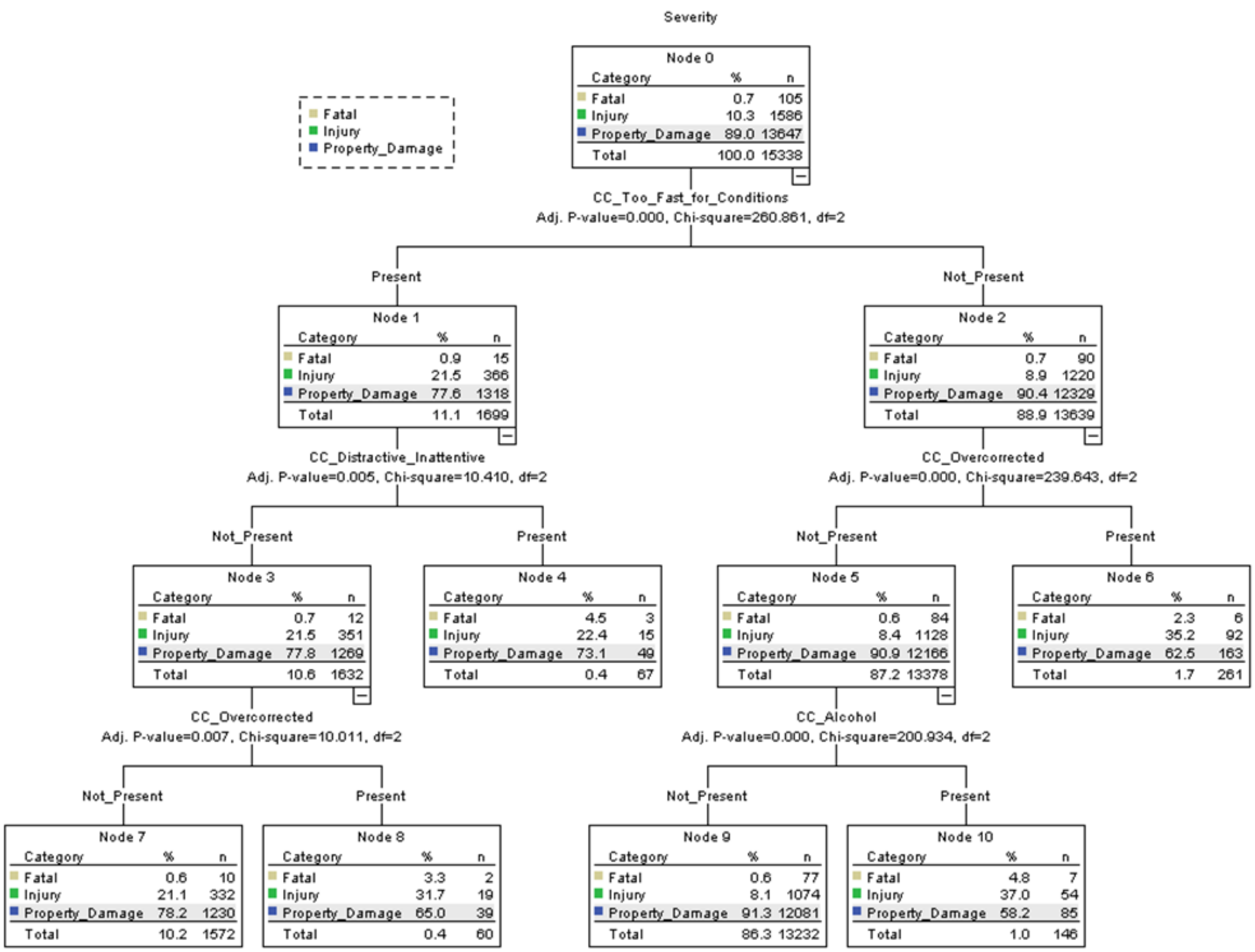

Figure 1. CHAID decision tree results for motor carrier drivers who contributed to a crash

Model results indicate that when driving too fast for conditions is present, the likelihood of a crash resulting in a fatal and injury outcome is 0.9% and 21.5%, respectively. When combining distracted/inattentive driving behaviors with driving too fast for conditions, the likelihood of a crash resulting in a fatal and injury outcome increases to 4.5% and 22.4%, respectively. Importantly, model results suggest that driving under the influence of alcohol is the most dangerous behavior examined, and the severity of crashes increase to 4.8% and 37.0% for fatal and injury outcomes, respectively.

Table 3 presents the results of calculating the upper and lower bounds for changes in the annual number of drivers involved in fatal, injury, and property damage only crashes by removing the contributing circumstance and assuming the crash still occurs with severity outcome probabilities determined by the outcome probabilities of the complementary node and by removing the contributing circumstance and assuming that the driver is not involved in a crash at all.

Table 3. Estimated reductions in number of drivers involved in each severity outcome if a contributing circumstance is eliminated

	Fatal		Injury		Property Damage Only		N[1]
Contributing Circumstance	**Est Lower Bound**	**Est Upper Bound**	**Est Lower Bound**	**Est Upper Bound**	**Est Lower Bound[2]**	**Est Upper Bound**	
Too Fast for Conditions	3	15	215	366	-218	1,318	1,699
Overcorrecting	4	8	77	111	-82	202	321
Distracted/ Inattentive Driving	2	3	1	15	-3	49	67
Alcohol Use	6	7	42	54	-48	85	146

[1]N = Number of estimated cases for the three-year period and equal to the sum of the estimated upper bounds.
[2]A negative value for property damage only outcome represents an increase for the least severe outcome, given the assumption that the crash still occurs.

If the significant contributing circumstances of driving too fast for conditions, distracted/inattentive driving, overcorrecting, and alcohol use are altered by AV and CV automation, it is suggested that between 117 and 193 severe crashes (fatal and injury outcomes) involving large trucks could be prevented annually in Missouri alone.

Consequently, key needs exist for AV and CV technologies for motor carriers to render such safety benefits by accounting for the significant contributing circumstances of driving too fast for conditions, overcorrecting, distracted/inattentive driving, and alcohol use. These needs include autonomously controlling acceleration, steering, monitoring of the environment, and responding to dynamic driving environments without the need for human intervention, as presented in Table 4.

Table 4. Comparison of SAE-defined levels (2016), AV/CV technologies, and crash contributing circumstances

SAE Level	Name	Execution of Steering and Acceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)	Contributing Circumstances
1	Driver Assistance	Human and System	Human	Human	Some driving modes	Overcorrecting
3	Conditional Automation	System	System	Human	Some driving modes	Too fast for conditions and Distracted driving
4	High Automation	System	System	System	Some driving modes	Alcohol use

Importantly, safe operation of a system that can perform these tasks autonomously, requires readable lane markings, traffic signals and signs, and dedicated refueling and/or recharging facilities. Additionally, arising from the deployment of CV technologies that facilitate truck platooning, managed lanes and infrastructure dedicated to AV/CV operations are needed to ensure the safe entering and exiting of highways.

CONCLUSIONS AND RECOMMENDATIONS

Although the infrastructure challenges from the deployment of AV and CV freight technologies are not insurmountable, they remain largely unexplored and inadequately investigated. This study outlines some key infrastructure needs for AV and CV technologies to be widely and safely used in the motor carrier industry. The first set of requirements is centered on the major tasks of an autonomous system to operate safely, which include autonomously controlling acceleration, steering, monitoring of the environment, and responding to dynamic driving environments without the need for human intervention. The safe operation of a system that can perform these tasks autonomously requires readable lane markings, traffic signals and signs, and dedicated refueling and/or recharging facilities. The deployment of truck platooning CV technologies necessitates an additional set of requirements that include managed lane or dedicated lane systems and accompanying infrastructure dedicated to AV/CV operations. Such infrastructure investments can be financially demanding, and public-private partnerships with motor carriers could help alleviate such burdens. These infrastructure requirements are determined based on safety as opposed to the efficiency of operations. In the interest of safety, it is wise to make the necessary infrastructure investments before the mainstream adoption of AV and CV technologies happens.

Limitations of this study do exist. First, it is difficult to predict when AV and CV technologies will be widely adopted, and two separate timelines must be considered: the development stages of the technology and the adoption stages of the developed technology. Elon Musk, chief executive officer (CEO) of Tesla, anticipates a fully autonomous Tesla car to be on the market by 2020, and many other motor companies have similar aspirations (Ohnsman 2017). Using Texas survey data and a multinomial logit model to predict market adoption rates of SAE level 4 autonomous cars, Kockelman et al. (2017) predict that 3.4% to 38.5% percent of households with at least one vehicle will adopt AV/CV technology by 2045. Second, this study only considers data from Missouri, while the implementation of such technologies would be nationwide. While translating the prediction of the rate of autonomous adoption to the motor carrier industry is complicated and states have varying levels of interest in acceptance, infrastructure requirements and safety concerns regarding the implementation of such technologies in the motor carrier industry require additional research efforts.

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