NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

Impacts of Connected, Automated Vehicle Technologies on Traffic Incident Management Response

NCHRP 20-102(16)

Intelligence Reports

Terminology

While connected vehicles (CV) and automated vehicles (AV) share many of the same operational goals, they operate using different mechanisms and technology. In areas where the discussion is separate to a particular technology (either AV or CV), the discussion separates out the context for each.

CVs have on-board equipment (OBE) that can transmit data to other devices internal to the vehicle and/or to external devices, services, vehicles, and infrastructure. The OBE can also receive and display safety warnings and other messages to the vehicle operator. A CV will be operated by a human driver.

AV (Level 3 to 5) are designed to be self-driving in some situations and employ software and hardware technologies to provide capabilities ranging from advanced driver assistance to completely automated driving.

CAV is used where there is no distinction to be made in the discussion of traffic incident management between CV and AV technologies.

RESPONDING TO AN INCIDENT

Problem Statement

Questions have been raised regarding the issues of how connected and automated vehicles might impact emergency vehicles. Specific areas of concern include:

- CAV's interaction with emergency response vehicles and personnel and what methods of communications will be utilized to facilitate this relationship.
- Adjustments in responder training and agency resources to effectively address incidents involving connected and automated vehicles since new response scenarios may arise from advances in vehicle technology.
- Responders prepared to navigate roadways possessing a heterogeneous mix of vehicles in automation capabilities.

Introduction

There are numerous information exchange capabilities for both CVs and AVs that may facilitate safer, more efficient, and effective incident response. For example, CVs may be able to move the information down the vehicle stream to help vehicles behind the incident to avoid the incident and perhaps reduce secondary incidents. Connective applications may also provide emergency response vehicles enhanced directions to avoid traffic, obstacles in the roadway, and other vehicles while traveling to an incident scene. AVs that are involved in an incident may be able to communicate specific information about the incident, scene and/or what emergency responders might face prior to numerous response personnel arriving on the scene. Other sections of this report outline other benefits CAVs may offer in incident response and challenges that may arise from their deployment.

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Potential Benefits

Table 1. Specific Vehicle Benefits

Opportunity	Automated	Connected
Labeling	• AV Identifier • Operational Status	• Messaging Confirmation
Connectivity	• Virtual Emergency Lanes	• Emergency Vehicle Navigation • Virtual Emergency Lanes

Labeling

The American Association of Motor Vehicle Administration has recommended labels on AV's sides and rears (GHSA, 2019; AAMVA, 2016) to help identify them among other vehicles. However, implementing this as a standard is challenging as it is unclear at this time on whether a national standard will be adopted (GHSA, 2019; AAMVA, 2016). It would also be beneficial to identify if the AV is being operated by the driver or ADS. The Governors Highway Safety Association (2019, pg. 24) reports that some AV developers are experimenting with colored lights to indicate this information to emergency response personnel but focus group discussion questioned if lighting will be consistent with existing lighting regulations.

Connectivity

Emergency Vehicle Navigation

Intersection Collision Avoidance

As stated by the U.S. Fire Administration, the most common place for emergency vehicles to collide with another vehicle is at an intersection (2014). Additionally, intersection collisions were the second leading cause of law enforcement motor vehicle related deaths from 1982 to 2012. These collisions are usually due to the other driver failing to yield to the emergency vehicle. By helping detect and warn responders of approaching vehicles at intersections, emergency response personnel can reduce their risk of collision at an intersection by reducing their speed or changing their travel direction. In one report, results found that intersection movement assist is feasible but further research and testing is needed (Rylex PSC and ITS-America, 2016).

Emergency Vehicle Traffic Signal Preemption

Connected vehicle technology can provide a variety of applications and benefits. In one study, connected technology was shown to provide a 34% decrease in emergency response times (Obenauf, 2019; Jordan et al., 2013). Another application of connectivity is connected vehicle traffic signal preemption systems designed to prioritize emergency vehicles (Rylex PSC and ITS-America, 2016). These systems would prioritize emergency vehicle's travel by giving them the right of way and reducing stops to help reduce travel and response times. Rylex PSC and ITS-America (2016) also reported two case studies, conducted in Fairfax County, VA and Plano, TX, where both deployments found benefits in reductions in travel time and number of crashes, respectively.

Virtual Emergency Lanes

Move over procedures performed manually could be eliminated altogether by implementing connected vehicle technology (Obenauf, 2019). Instead, CAVs could work cooperatively to create a virtual emergency lane (VEL). VELs could help eliminate human indecision and error resulting in reduced response times. In a study conducted by Obenauf (2019), researchers modeled the effectiveness of VELs under three levels of connected and automated vehicle scenarios (0%, 50%, and 100%) (TSAG, 2020). Results showed significant reductions in response times for emergency response personnel.

Potential Challenges

Table 2. Specific Vehicle Challenges

Challenge	Automated	Connected
Move Over Procedures	• Emergency Vehicle Detection emergency response vehicle. • Executing Correct Move Over Maneuver	• Communication Mechanism between CVs and Emergency Vehicles
Identification and Feedback	• Detection Confirmation • Operational Status	• Messaging Confirmation
Training	• Preparing for a Mixed Fleet	

Move Over Procedures

Move over laws support incident response by directing drivers approaching an incident scene to provide space for emergency vehicles' timely and safe response to an incident. Drivers are currently notified via emergency vehicle lights, sirens, and horns to move over and create a clear path for emergency vehicles to pass.). According to one study that conducted several focus groups and one-on-one interviews with emergency responders, participants expressed concern with how AVs will recognize these cues and respond to emergency response vehicles in general (Terry et al., 2018). Technology and design challenges emerge in determining how AVs will recognize these cues and respond to actuated traffic signal preemption or execute the appropriate move-over maneuver (TSAG, 2020: Terry et al., 2018Communication challenges with CVs may also develop in terms of how and what information will be broad casted as emergency vehicles are approaching.

Participants also mentioned that although automated vehicles could be programmed to perform move-over maneuvers for emergency vehicles, there may be scenarios requiring other maneuvers, safer for the given circumstances, that automated vehicles were not programmed to execute (Terry et al., 2018). Participants suggested potentially possessing the authority to influence how the vehicle would divert to combat this problem. Implementing this type of authority would give emergency responders better insight and predictability into how vehicles will respond but offer them flexibility, provided that roadway conditions are dynamic and constantly changing. Further research should also examine if initiating take-over requests to transition control from the automated driving system (ADS) to the driver to perform a move-over maneuver is best.

Identification Feedback

In the same focus group (Terry et al., 2018), participants mentioned the importance of possessing the capability to identify an AV and its current operational mode, specifically while in the driverless mode. Identifying an AV can allow dispatch to inform emergency response personnel in initial lines of communication and enable agencies to reevaluate risk and deploy the necessary resources to handle these incidents. Furthermore, while emergency responders navigate traffic to the incident scene, they can better predict driving behavior and respond accordingly to prevent secondary crashes if they can identify AVs along their route.

Participants also recommended that AVs provide feedback to the emergency vehicle drivers that they detect their vehicle approaching to enhance safety and communication. A visual cue indicating the vehicle and driver are receiving information can inform emergency response personnel on how to interact with these vehicles. Similarly, CVs should also be able to communicate feedback and confirm crucial information is being received so the vehicle or driver can act accordingly. As connectivity increases and provides more assistance to the driver, the risk of the driver being disengaged from the task of driving may increase.

Training and Preparing for a Mixed Fleet

The emergency response community will have to respond to the issues that develop from the interaction of a mixed fleet. Training requirements for emergency responders will have to become more robust to develop expertise for a diverse fleet of roadway vehicles differing in automation and connectivity abilities which may impact their coordination and response (GHSA, 2019).

Public outreach between CAV manufacturers and emergency responders will become critical to this process to ensure both parties understand their evolving responsibilities and risk as CAV technology develops. It may also be beneficial to include and engage the public in this discussion and provide tailored material to educate them on CAVs (GHSA, 2019). Furthering the public's understanding of CAVs, including their benefits and limitations, could promote roadway safety and offer perspective to enhance emergency response training involving CAVs.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

<table>
<tr><th>Information</th><th>Definition</th><th>AV Impact</th><th>CV Impact</th></tr>
<tr><td>Incident Location</td><td>Specific location of where the incident took place</td><td colspan="2">AV and CV could provide precise location of incident to emergency response personnel and directions.</td></tr>
<tr><td>AV Involvement*</td><td>Whether or not a CV and or AV was involved</td><td>First responders and civilians will have to be able to identify an AV to report its involvement in an accident. Reporting this information could help emergency response personnel better prepare and deploy the necessary resources.</td><td></td></tr>
</table>

<table>
<tr><th>Information</th><th>Definition</th><th>AV Impact</th><th>CV Impact</th></tr>
<tr><td>Incident Information</td><td>All details of the incident that took place such as number of vehicles involved, condition of vehicles and systems, number of people involved, severity of injuries, urgency, etc.</td><td colspan="2">As CV/AVs emerge, new problems and incidents may arise such as electrical fires, malfunctioning software, etc.</td></tr>
<tr><td>Knowledge of Resources Needed at the Incident Scene</td><td>What agencies and resources will be needed at the incident to provide the most effective response (i.e., if there are injuries EMS will be needed)</td><td colspan="2">Not only will these scenarios have to be identified but agencies must be trained and prepared to deploy the necessary resources to combat them.</td></tr>
<tr><td>Road and Optimal Route Conditions</td><td>Current road and route conditions that may impact travel such as construction, weather, traffic, etc.</td><td>AV/CVs may impact travel of response vehicles and must be able to appropriately react and/or communicate to response vehicles passing.</td><td>CVs could enhance travel to an incident by providing emergency response vehicle drivers with more detailed information regarding road conditions and other vehicles.</td></tr>
</table>

** New Information Streams with CV/AV Implementation*

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SECURING A SCENE

Problem Statement

Securing an incident is a dynamic process that heavily relies on emergency responders creating visuals and using other traffic control devices to signal drivers to adjust their driving and move around a scene to prevent secondary accidents. It is unclear how CAVs may respond to these traffic diversion methods and how communication between them and emergency response personnel will adapt once deployed. More specifically, additional challenges emerge, such as:

- CAV's detection and response to traffic control devices, including temporary traffic signals and lane delineators such as message boards, flaggers, flares, cones, LEDs, or even law enforcement hand signals.
- Establishing new communication methods with CAVs so emergency personnel can identify them and vice versa. Other design concerns emerge in messaging, such as the warning mode, frequency, lead time, and feedback.
- Emergency response personnel overcoming gaps in training and knowledge to prepare for new risks posed by advanced vehicle technology like electrical fires or software errors.

Introduction

There are numerous information exchange capabilities for both CVs and AVs that may facilitate securing the scene of an incident in a safer, more efficient, and effective manner. For example, CVs may be able to move the information down the vehicle stream to help vehicles behind the incident to avoid the incident and perhaps reduce secondary incidents. CAVs may also communicate the precise location of the incident to reduce travel times, confirm incident information prior to numerous response personnel arriving on the scene, assess risk factors, and help determine if additional resources are required to provide further aid. Other sections of this report outline other benefits CAVs may offer in incident response and challenges that may arise from their deployment.

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Potential Benefits

Table 1. Specific Vehicle Benefits

<table>
<tr><th>Opportunity</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Traffic Safety Alerts</td><td></td><td>• V2V Communication</td></tr>
<tr><td>Investigation Protocols</td><td colspan="2">• Persevering onboard data to help investigation</td></tr>
</table>

Traffic Safety Alerts

Maintaining the safety of emergency responders is crucial while securing an incident scene. According to FHWA, struck-by incidents are the second leading cause of accidental law enforcement death and account for 20% of on-duty firefighter deaths yearly (Owens, 2009; CDC, 2022). Furthermore, the likelihood of secondary crashes increases by 2.8% for each minute the primary incident continues to be a hazard (Owens, 2009, pg. 20).

By leveraging vehicular communication systems, connected vehicles may offer emergency responders additional traffic information to avoid injury. One report indicated this may include providing on the scene emergency responders audible alerts of upcoming traffic with enough time to take the appropriate precautions and protective positions (Rylex PSC and ITS-America, 2016). Conversely, connective applications may also offer warnings to drivers approaching the incident scene to increase attention or potentially detour and avoid the scene altogether.

Investigation Protocols

As CAV technology advances and operates in a heterogeneous mix of vehicles, accident causes will become more complex and essential to study to enhance road safety. Persevering onboard data in the event of an accident involving a CAV may provide specific information to help investigators determine who is at fault and help with other crash reporting and investigating responsibilities (TSAG, 2020). Detailed information this data could provide includes, but is not limited to, the mode of the vehicle at the time of the accident, the operator's engagement, potential software malfunctions and errors, and so forth. However, there are concerns about who can access this data and the ethical responsibilities while handling it (i.e., altering information) (Terry et al., 2018).

Potential Challenges

Table 2. Specific Vehicle Challenges

<table>
<tr><th>Challenge</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Disabling Vehicle Power Source</td><td colspan="2">• Electrical fire prevention knowledge and training
• Collaboration with manufacturers to provide guidance on disabling a CAV safely</td></tr>
<tr><td rowspan="2">Identifying and Securing AV</td><td>• AV Identifier
• Detection Confirmation
• Operational Status</td><td>• Messaging Confirmation</td></tr>
<tr><td colspan="2">• Obtaining design specifications and other documentation to disable vehicle</td></tr>
</table>

Challenge	Automated	Connected
Roadway Clearance	• Specialty Equipment Requirements	
Diverting Traffic	• Detection Accuracy to Traffic Control Devices • Executing appropriate response to traffic control devices	• Communication Mechanism

Disabling CAV Power Source

Several studies have mentioned that disabling the power source to a CAV would be the priority at an incident scene to prevent any hazardous scenarios such as electrical fires from occurring (TSAG, 2020). Although not all CAVs are electric vehicles, many use this technology which mostly implement lithium-ion batteries (TSAG, 2020). Groups like the U.S. Fire Administration (2019) indicate specific, unique risks associated with lithium-ion battery fires that conventional extinguish methods cannot always help making them more dangerous than conventional vehicle fires.

For example, lithium-ion batteries are more difficult to treat and could require thousands of gallons of water to extinguish. In some scenarios, applying water could make the fire worse and, unfortunately, emergency responders do not always have access to the appropriate chemical agents or thousands of gallons of water to resolve the fire (USFA, 2019). Lithium-ion battery fires also include increased risk for reignition for up to 24 hours, electrical shock, and lithium burns (USFA, 2019). First responders need education and ready access to vehicle manufacturer documents outlining the unique features and safety protocols to avoid such injuries and hazards. Examples of such documents include Fiat Chrysler Emergency Response Guide for the 2017 Chrysler Pacifica Hybrid (Fiat 2017). Others have also speculated disabling a vehicle could be potentially accomplished by use of the vehicle's key fob, cutting the battery cables, or requesting an occupant familiar with how the vehicle operates to disable it (Terry et al., 2018).

Identifying and Securing AV

The emergency response community has indicated the priority in securing an incident scene would be to disable the AV's power source to reduce the risk of potential hazards, but also to prevent the vehicle from moving (AVSC SAE, 2020; TSAG, 2020; Terry et al., 2018). Disabling the vehicle at the scene would also prevent further movement and potentially other injuries to responders or bystanders. However, before emergency response personnel can disable the vehicle, they will have to identify the vehicle as an AV and obtain specific vehicle information to cut the power source safely from documents such as design specifications and information from the manufacturer.

It will have to be made apparent that the vehicle they are approaching is an AV, including its current operational mode. Emergency personnel will have to be trained to not only identify AVs and their current operational mode but as well as how they will navigate around them to avoid being struck. It is unclear whether AVs could provide visual feedback to responders regarding detection and the state of operation. Focus group participants of emergency responders mentioned receiving this feedback would help increase their comfortability since post-accident AV behavior could be unpredictable (Terry et al., 2018). If the vehicle is confirmed to be an AV, emergency responders may have to barricade it until they can disable it (Terry et al., 2018). New protocols for securing an incident scene may have to be developed to promote safe practices in these scenarios and discuss potential new secondary accident types that may emerge from AV development.

Roadway Clearance

Once an AV (or CV) is disabled, emergency responders will have to clear the roadway by moving the vehicle so traffic can resume to normal as quickly as possible (Terry et al., 2018). Typically, vehicles are moved from the roadway through tow trucks or response vehicles' push bumpers. Collaboration and discussion need to occur between emergency response agencies and AV manufacturers regarding towing and clearance procedures, especially if there is substantial damage to the AV. It is currently unclear what towing requirements for AVs are and if they will differ from current towing procedures and or require specialized equipment (TSAG, 2020). If there is no substantial damage, responders also recommend having the ability to communicate with the vehicle to move to the shoulder (Terry et al., 2018).

Diverting Traffic

Often, securing an incident scene involves diverting traffic around the incident to prevent secondary accidents and keep emergency responders safe while tending the scene. Like move-over laws, emergency response personnel create visual cues to indicate to drivers to follow a specific path that may vary from the road's design and geometry. There is significant concern about how CAVs, particularly AVs, will navigate around accident scenes and respond to temporary traffic signals and lane delineators such as message boards, flaggers, flares, cones, LEDs, or even law enforcement hand signals (Terry et al., 2018). It is uncertain if emergency response personnel will need to utilize new equipment or markings to improve communication with CAVs to navigate incident scenes safely.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

Information	Definition	AV Impact	CV Impact
Precise Incident Location	A more precise location of where the incident took place (i.e., street names, mile markers, nearby interchanges, etc.)	AV and CV could provide precise location of incident to emergency response personnel and directions.	
AV Involvement*	Whether or not a CV and or AV was involved	Identifying an AV, specifically if involved in the accident, will be essential for emergency responder's safety. AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.	

<table>
<tr><th>Information</th><th>Definition</th><th>AV Impact</th><th>CV Impact</th></tr>
<tr><td>Vehicle Information</td><td>Details relating to the vehicle(s) involved in the accident like damage sustained, orientation, location in the roadway, number of vehicles, etc.</td><td>AVs may require specialty equipment to move out of the roadway to prevent more damage or other hazards.</td><td></td></tr>
<tr><td>Occupant Information</td><td>All information relating to occupants involved in the accident, including number of people involved, number injuries, severity of injuries, condition of occupants, etc.</td><td></td><td></td></tr>
<tr><td>Need for Extraction</td><td>Whether or not occupant(s) will need to be extracted from vehicle</td><td colspan="2">Specific expertise may need to be deployed if an occupant is trapped inside a CAV. Manufacturers may need to provide guidance to disable the vehicle safely to avoid further injury to the occupant or emergency response team.</td></tr>
<tr><td>Potential Hazards</td><td>Communicate details regarding active or potential hazards at the scene</td><td colspan="2">CAVs may require emergency responders training to be adapted to account for other potential hazards that may arise that are exclusive to automated and connected vehicle technologies.</td></tr>
</table>

** New Information Streams with CV/AV Implementation*

References

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PROVIDING TRAFFIC DIRECTION AND CONTROL

Problem Statement

New technological opportunities develop in determining how CAVs will respond to manual traffic direction and control. Specific challenges include:

- CAVs detecting emergency responders directing traffic and manual override changes in traffic control devices.
- CAV response to changes in the roadway to redirect traffic and traffic control devices (i.e., cones, lane delineators, caution lights, etc.) that may violate the roadway's design and traffic laws.

Introduction

There are numerous information exchange capabilities for both CVs and AVs that may facilitate providing traffic direction and control in a safer, more efficient, and effective manner. For example, CVs may be able to move the information down the vehicle stream to help with traffic flow, redirection, and control. CAVs may also communicate the precise locations such as special events, natural disasters, malfunctioning traffic control devices, severe weather conditions, and vehicle accidents (Terry et al., 2018; Florida Highway Patrol, 2015). The use of emerging connected communication technologies for smart work zones that provide real-time data using Bluetooth, volume sensors, intelligent roadside cones, smart safety vests and CCTV cameras may be employed to assess conditions and report information to assist response personnel in their duties. Other sections of this report will outline other benefits CAVs may offer in traffic direction and control and challenges that may arise from their deployment.

Potential Benefits

Table 1. Specific Vehicle Benefits

Opportunity	Automated	Connected
Efficient Rerouting	• Reliable and Consistent Response	• V2V Communication
Traffic Safety Alerts		• V2V Communication

Efficient Rerouting and Traffic Safety Alerts

It is crucial for emergency response personnel to remain visible and in a defensive position while redirecting traffic to avoid being struck. Current injury mitigation methods include increasing their saliency by wearing retroreflective and glow-in-the-dark garments, being mindful of where they stand among traffic, and implementing other standard practices to enhance their safety, like making eye contact with drivers. Deploying connected and automated vehicles may enhance safety through vehicle communication methods and increased reliability. For example, deploying automated vehicles may mitigate human error and be safely rerouted regardless of whether the driver is attentive. Connected communications may also provide drivers more information to be rerouted more efficiently and communicate detours instead of emergency response personnel. As a result, driver behavior may be less varied, and fewer resources and personnel may be needed at a scene or event to reroute drivers (Terry et al., 2018).

Potential Challenges

Table 2. Specific Vehicle Challenges

Challenge	Automated	Connected
Communication with Emergency Responders	• AV Identifier • Emergency Responder Detection • Executing Correct Response to Rerouting Cues	• Communication Mechanism between CVs and Emergency Responders • Messaging Confirmation
Roadway Violations	• Respond appropriately to purposeful roadway violations	
Traffic Control Devices	• Detection Traffic Control Devices • Adapt Operations to Traffic Control Devices	
Planned vs Unplanned Events	• Quickly adapt operations to unplanned events	

Communication between Emergency Responders and CAVs

An integral part of redirecting traffic is emergency responders communicating with vehicles through hand gestures, eye contact, body language, and or verbally where to go. In a focus group with emergency response personnel conducted by Terry et al. (2018), participants expressed concern about whether CAVs could follow these types of instructions and how the varying levels of automation will respond. More importantly, whether CAVs can detect emergency responders on the roadway and distinguish them from other pedestrians.

Further ideas were discussed among the focus group regarding if new technology will have to be developed so emergency responders can better communicate with CAVs, interact with them safely, and reroute them accordingly. Participants also reasoned that if CAV designers could not establish proper communication between CAVs and emergency responders, this could create a hazard on the roadway. Scenarios like the CAV blocking traffic or not coming to an appropriate stop could arise if it is unsure how to navigate in areas where traffic is being redirected. Hence, emergency response personnel must be able to identify CAVs among traffic.

Roadway Violations

One aspect of redirecting and controlling traffic because of an unplanned or preplanned event is that vehicles may have to navigate along a route that violates the roadway's design and laws. For example, this could include navigating the wrong way of a one-way street, utilizing a normally prohibited U-turn, driving on the shoulder, etc. (Terry et al., 2018). CAVs will have to be able to respond to these scenarios safely or possess the capability to know when to resume from automated driving system (ADS) to driver control.

Traffic Control Devices

Emergency responders will often utilize various traffic control devices to redirect traffic like temporary signage, cones, flares, lane delineators, lane markings, message boards, caution lights, and so forth (Terry et al., 2018). It is unclear how CAVs will interact with these tools and if they will inadvertently cause CAVs confusion. CAV designers should consider these interactions and communicate with agencies if they need new devices to prepare them for CAV deployment. Work zone tools could be applied here such as traffic cones embedded with sensors and smart vests with the ability to transmit real-time data (Roofigari et al., 2021).

Planned vs Unplanned Events

Circumstances that require traffic direction and control can either be planned or unplanned events. Planned events are ones where agencies are aware of the event before it occurs, like a sports game, conference, or concert where high traffic volumes will occur. Unplanned scenarios are unexpected, like vehicle incidents, malfunctioning traffic control devices, and sudden adverse weather conditions.

The deployment of CAVs may impact how agencies deploy resources for both event types and may require further consideration, specifically if the event is unplanned and specific resources are not yet deployed. CAVs will have to react appropriately to unexpected events and resulting natural traffic behaviors (i.e., slowing traffic, preemptively exiting the freeway, etc.), especially if advanced warnings and other redirection methods were not yet deployed.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

Information	Definition	AV Impact	CV Impact
Incident Location	Specific location of unplanned event (i.e., accident) or planned event (i.e., concert, sport competition, etc.)	Different considerations will have to be made regarding if an event is planned or not. CAVs will have to adapt to scenarios that were unplanned appropriately respond before communication devices could potentially be deployed.	
Route Options	Available route options to redirect traffic efficiently	The deployment of CAVs may pose different requirements in choosing rerouting options to accommodate a mixed group of vehicles and potentially provide space for appropriate communication infrastructure, if needed.	
Resources and Tools to Reroute Vehicles	Traffic control devices and other tools needed to redirect traffic safely	CAVs may require special equipment to communicate rerouting and other changes in the roadway are detected and navigated safely.	

** New Information Streams with CV/AV Implementation*

References

Florida Highway Patrol. (2015). Florida Highway Patrol Policy Manual. Tallahassee: Florida Highway Patrol.

Terry, T., Trimble, T. E., Blanco, M., Fitzgerald, K. E., Fitchett, V. L., and Chaka, M. (2018). An Examination of Emergency Response Scenarios for ADS. Farmington Hills, MI: Crash Avoidance Metrics Partners LLC.

Roofigari-Esfahan, N., White, E., Mollenhauer, M., Talledo Vilela, J.P. 2021. Development of a Connected Smart Vest for Improved Roadside Work Zone Safety. https://vtechworks.lib.vt.edu/bitstream/handle/10919/104207/Safe-D_Report_Smart-Vest_04-104.pdf?sequence=1&isAllowed=y

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Impacts of Connected, Automated Vehicle Technologies on Traffic Incident Management Response

NCHRP 20-102(16)

Intelligence Reports

Terminology

While connected vehicles (CV) and automated vehicles (AV) share many of the same operational goals, they operate using different mechanisms and technology. In areas where the discussion is separate to a particular technology (either AV or CV), the discussion separates out the context for each.

CVs have on-board equipment (OBE) that can transmit data to other devices internal to the vehicle and/or to external devices, services, vehicles, and infrastructure. The OBE can also receive and display safety warnings and other messages to the vehicle operator. A CV will be operated by a human driver.

AV (Level 3 to 5) are designed to be self-driving in some situations and employ software and hardware technologies to provide capabilities ranging from advanced driver assistance to completely automated driving.

CAV is used where there is no distinction to be made in the discussion of traffic incident management between CV and AV technologies.

EXECUTING TRAFFIC STOPS AND CHECKPOINTS

Problem Statement

Like many other tasks performed by public safety officials, police rely on providing drivers visual and sometimes auditory cues to come to a stop and or be redirected to a checkpoint. The few decisions drivers must make to come to a stop require intuition and evaluation of their surroundings to adapt their driving behavior and find a safe place to stop. With the development of CAVs, research indicates some challenges to arise specific to this emergency response task:

- It is unclear if CAVs will possess this intuition to distinguish a safe place to stop or even know when to stop at the signal of police lights or redirection cues for a checkpoint.
- Design challenges also emerge in what types of feedback the CAV could provide the pursuing officer to confirm detection and communicate other information, including potential malfunction.

Introduction

Traffic stops are meant to convince the vehicle to pull over safely for law enforcement. These stops are usually performed whenever a vehicle is not abiding by traffic laws. Although CAVs present several challenges to this task, such as detection and response concerns, if addressed, facilitating a traffic stop may become more manageable regarding access to driver information, reliable vehicle behavior, and response. Further discussion regarding potential challenges and benefits is outlined in the remaining sections of this report.

Potential Benefits

Table 1. Specific Vehicle Benefits

Opportunity	Automated	Connected
Improved Response	• Reliable Vehicle Behavior and Response	• V2V Communication
Investigation Protocols		• Access to Driver Information

Improved Response

Some stops may be more severe than others regarding the violation and suspected crime. In some cases, law enforcement may require additional backup if a felonious act is suspected and witnessed. Checkpoints are similar in that they are meant to inspect the motorist and their vehicle safely but are preplanned, unlike traffic stops. These stops can entail searching for a specific vehicle and/or person, sobriety checks, license checks, etc. Not only could vehicle communications via connected vehicles potentially provide law enforcement with more information relating to the driver and operational status of the vehicle but improve communication between law enforcement and the driver to stop. Other automated responses may also assist the driver in finding a safe location to pull over or force a stop altogether if a driver refuses to pull over manually. Some of these applications could potentially improve law enforcement safety and their response; however, many of these benefits will have to be further researched and studied.

Investigation Protocols

Before police engage in a stop, specific details are collected and communicated to dispatch, such as vehicle information and the number of occupants in the vehicle. These details are communicated to protect the officer and determine if the driver has warrants or previous offenses. Through vehicle communications, law enforcement may be able to access this information, and more, quickly to help facilitate a stop more easily. Additionally, communications and other feedback from the vehicle could offer details regarding the vehicle's operational status if a mechanical or software issue is being experienced.

Potential Challenges

Table 2. Specific Vehicle Challenges

<table>
<tr><th>Challenge</th><th>Automated</th><th>Connected</th></tr>
<tr><td rowspan="2">Initiating Stop</td><td>• Detection</td><td>• Communication Mechanism</td></tr>
<tr><td colspan="2">• Facilitating appropriate response (i.e., pulling over in safe location)</td></tr>
<tr><td>CAV Identification and Feedback</td><td>• Detection Confirmation
• Operational Status</td><td>• Messaging Confirmation</td></tr>
</table>

Initiating a Stop

Multiple studies have reported concerns about how CAVs will respond to lights and sirens (TSAG, 2020; Terry et al., 2018). Specifically, if CAVs, in driverless operation, will know to stop for law enforcement during a routine traffic stop. One study reported that officers expressed during a focus group that not only were they concerned about if and how a CAV would pull over for them, but if the CAV would also be capable of pulling over in a location that is safe for both the passenger and the officer (Terry et al., 2018).

CAV Identification and Feedback

CAVs must offer feedback, specifically while in driverless mode, to inform law enforcement of their current operational mode and automation ability. Law enforcement possessing this information would help facilitate an appropriate and safe interaction between them and the vehicle itself, which could be communicated to other agencies immediately if needed. It would also allow officers to assess how much the driver is responsible versus the vehicle itself. For example, if the vehicle were malfunctioning, officers would better understand how to approach the vehicle and predict its behavior at a stop or checkpoint if they received this feedback (Terry et al., 2018). Other questions from this scenario also arise, such as law enforcement training to help assist a driver in a malfunctioning CAV and whether officers will be able to pull data from the vehicle to better their assistance.

Beyond identifying if the subject vehicle is a CAV or not and its current operational mode, other forms of feedback from the CAV would also improve law enforcement response and safety. For example, CAV confirms if it has received the message to stop as this could be another type of malfunction. Furthermore, the CAV indicates whether it intends to stop or not and or cannot stop. If it does intend to stop, the CAV indicating when and where would provide law enforcement information to increase their comfortability. Once the vehicle is pulled over, feedback that the vehicle will remain stopped promote could help improve law enforcement safety. However, new discussions on procedures may arise to evaluate if drivers should take on new practices to increase their personal safety and law enforcement, such as powering down the vehicle to ensure it does not move at a stop.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

<table>
<tr><th>Information</th><th>Definition</th><th>AV Impact</th><th>CV Impact</th></tr>
<tr><td>CAV Involvement*</td><td>Whether or not a CV and or AV is being pulled over</td><td colspan="2">It is essential to response to understand if a vehicle involved in a traffic stop is considered a CAV. Understanding the vehicle's technological abilities may influence how law enforcement approaches the vehicle and prepare for any associated risks and other malfunctions not common in standard vehicles.</td></tr>
</table>

Information	Definition	AV Impact	CV Impact
Number of Occupants		AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.	
Driver and Vehicle Information	Information relating to the driver (i.e., vehicle registration, proof of insurance, driver's license, etc.) of the vehicle and other vehicle information (make, model, year, operational status, etc.)		Connected vehicles may offer communication channels to allow law enforcement driver information with more ease or more detailed information (i.e., operational status of the vehicle, state of the driver, etc.)
Reason for Stop	Reason for traffic stop		

** New Information Streams with CV/AV Implementation*

References

Automated Vehicle Safety Consortium. 2020. Best Practice for First Responder Interactions with Fleet-Managed Automated Driving System-Dedicated Vehicles (ADS-DVs). SAE Industry Technologies Consortium

Governors Highway Safety Association (GHSA). 2019. Automated Vehicle Safety Expert Panel: Engaging Drivers and Law Enforcement. https://www.ghsa.org/sites/default/files/2019-08/AV%20Safety%20White%20Paper_FINAL.pdf

ITE and Pat Noyes & Associates. CV/AV Needs Specific to Emergency Response White Paper. 2020. https://mva.maryland.gov/safety/Documents/CV-and-AV-Needs-Specific-to-Emergency-Response-White-Paper-Final.pdf

Terry, T., Trimble, T. E., Blanco, M., Fitzgerald, K. E., Fitchett, V. L., and Chaka, M. (2018). An Examination of Emergency Response Scenarios for ADS. Farmington Hills, MI: Crash Avoidance Metrics Partners LLC.

STABILIZATION AND EXTRICATION

Problem Statement

There is still uncertainty surrounding issues of how to stabilize a connected and automated vehicles so that emergency response personnel can safely extricate trapped occupants. CAVs may represent a greater risk during traffic incidents due to their hardware and other technological capabilities. Specific areas of concern include:

- Emergency response personnel overcoming gaps in training and knowledge to prepare for new risks posed by advanced vehicle technology like electrical fires or software errors.
- Previous protocols for stabilizing the vehicle and extracting occupants will need modified to account for CAVs advanced design and technological capabilities.
- CAVs may require specialized equipment, access to vehicle specific protocols and additional training.

Introduction

Fire and rescue first must stabilize the vehicle to ensure it does not move during extrication. Once the vehicle is stabilized, fire and rescue will extricate trapped occupants as safe as possible. Current guidelines and training involving the stabilization and extrication of an electric vehicle may need to be revised to include CAVs. As vehicles advance towards CAV deployment, fire and rescue personnel will need extensive training to understand further the potential hazards that could emerge from these tasks as well as understand how to perform these tasks safely.

Intelligence Reports

Terminology

While connected vehicles (CV) and automated vehicles (AV) share many of the same operational goals, they operate using different mechanisms and technology. In areas where the discussion is separate to a particular technology (either AV or CV), the discussion separates out the context for each.

CVs have on-board equipment (OBE) that can transmit data to other devices internal to the vehicle and/or to external devices, services, vehicles, and infrastructure. The OBE can also receive and display safety warnings and other messages to the vehicle operator. A CV will be operated by a human driver.

AV (Level 3 to 5) are designed to be self-driving in some situations and employ software and hardware technologies to provide capabilities ranging from advanced driver assistance to completely automated driving.

CAV is used where there is no distinction to be made in the discussion of traffic incident management between CV and AV technologies.

Potential Benefits

Table 1. Specific Vehicle Benefits

Opportunity	Automated	Connected
Improved Response		• V2V Communication
Investigation Protocols	• Persevering onboard data to help investigation	

Improved Response

Occupants rarely need to be extricated from their vehicle after a motor vehicle collision. According to one study, these cases only accounted for 1% of all fire and rescue responses in 2014 (Ahrens & Evarts, 2017; Terry et al., 2018). Despite these cases' frequency, however, their impact can be severe to everyone involved, such as the passenger(s) trapped, responders, and other roadway users, and makes them a priority to resolve as quickly as possible. Utilizing vehicle communications could potentially facilitate new communication streams between the vehicle and emergency responders that can help expedite the extraction process. Information may include confirming occupants are trapped, deploying messaging to fire and rescue an extraction is needed, or guidance to disable the vehicle.

Investigation Protocols

Accident causes will become more complex as vehicle technology progresses towards automation and connectivity. Persevering onboard data in the event of an accident involving a CAV may provide specific information to help investigators determine who is at fault and help with other crash reporting and investigating responsibilities (TSAG, 2020). In the case of extracting occupants from a vehicle, preserving onboard data could provide investigators a better understanding of the series of events leading to an extraction. Furthermore, enhanced data may help guide future CAV extraction tasks.

Potential Challenges

Table 2. Specific Vehicle Challenges

Challenge	Automated	Connected
Identifying CAV Operation Status	• Ascertain the vehicle's operational mode, whether that be standby, currently operable, malfunctioning, or if the vehicle needs help	
Disabling CAV Power Source	• Electrical fire prevention knowledge and training • Collaboration with manufacturers to provide guidance on disabling a CAV safely and obtaining design specifications and other documentation to enable vehicle stabilization	

<table>
<tr><th>Challenge</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Identifying and Securing AV</td><td>• AV Identifier
• Detection Confirmation
• Operational Status
• Obtaining design specifications and other documentation to disable vehicle</td><td></td></tr>
<tr><td rowspan="2">Training and Specialized Equipment</td><td colspan="2">• Training requirements and curriculum will need to be adapted to include CAVs in stabilization and extrication protocols</td></tr>
<tr><td>• Detection Accuracy to Traffic Control Devices
• Executing appropriate response to traffic control devices</td><td>• Communication Mechanism</td></tr>
</table>

Identifying CAV and Operational Status

Fire and rescue must be notified by dispatch as soon as possible on the type of vehicle that needs extrication and its operational mode (Terry et al., 2018). Having this information as quickly as possible can help improve response time and preparedness in the case of a CAV incident.

Disabling CAV Power Source

An integral step in extricating a trapped occupant from their vehicle is first stabilizing the vehicle. Stabilization is done to immobilize the vehicle and prevent movement to create a safe environment for responders and avoid further injury to the passenger (AVSC, 2020). With CAVs, stabilization may be a more complex process for responders if the vehicle is experiencing a software malfunction. They first may need to secure the area with barricades to prevent struck by incidents (Terry et al., 2018).

Once the vehicle is secured, disabling the CAVs power source becomes the next challenge. Many have mentioned that disabling the power source would be a high priority to prevent any hazardous scenarios (TSAG, 2020; Terry et al., 2018), but this task will become especially significant and timely in extrication cases. It is unclear on what training or correspondence will occur between responders and CAV manufacturers regarding disabling the power source.

Training and Specialized Equipment

Training requirements and curriculum will need to be adapted to include CAVs in stabilization and extrication protocols. Fire and rescue personnel will need to further understand what hazards could arise with these types of vehicles and acquire the proper skills to handle them (i.e., CAV power source, vehicle interior, software malfunctions, etc.). Different protocols may need to be executed, special tools utilized, and specific personnel with specialized expertise to handle such incidents.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

Information	Definition	AV Impact	CV Impact
Precise Incident Location	A more precise location of where the incident took place (i.e., street names, mile markers, nearby interchanges, etc.)	AV and CV could provide precise location of incident to emergency response personnel and directions.	
AV Involvement*	Whether or not a CV and or AV was involved	Identifying an AV, specifically if involved in the accident, will be essential for emergency responder's safety. AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.	
Vehicle Information	Details relating to the vehicle(s) involved in the accident like damage sustained, orientation, location in the roadway, number of vehicles, etc.	AVs may require specialty equipment to move out of the roadway to prevent more damage or other hazards.	
Occupant Information	All information relating to occupants involved in the accident, including number of people involved, number injuries, severity of injuries, condition of occupants, etc.		

Information	Definition	AV Impact	CV Impact
Need for Extraction	Whether or not occupant(s) will need to be extracted from vehicle	Specific expertise may need to be deployed if an occupant is trapped inside a CAV. Manufacturers may need to provide guidance to disable the vehicle safely to avoid further injury to the occupant or emergency response team.	
Potential Hazards	Communicate details regarding active or potential hazards at the scene	CAVs may require emergency responders training to be adapted to account for other potential hazards that may arise that are exclusive to automated and connected vehicle technologies.	

** New Information Streams with CV/AV Implementation*

References

Ahrens, M., & Evarts, B. (2017). Fire Department Roadway and Vehicle Incidents. In: NFPA.

Automated Vehicle Safety Consortium (AVSC). 2020. Best Practice for First Responder Interactions with Fleet-Managed Automated Driving System-Dedicated Vehicles (ADS-DVs). SAE Industry Technologies Consortium.

ITE and Pat Noyes & Associates (TSAG). CV/AV Needs Specific to Emergency Response White Paper. 2020. https://mva.maryland.gov/safety/Documents/CV-and-AV-Needs-Specific-to-Emergency-Response-White-Paper-Final.pdf.

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PROVIDING MOTORIST ASSISTANCE

Problem Statement

Questions are raised regarding the issues of providing motorist assistance when a CAV is involved. CAVs may represent a greater risk if parked in a potentially dangerous location. Specific areas of concern include:

- The ability of AVs to respond to an operational or mechanical issue and move to a safe location is vital for traffic safety.
- Many CAVs are electric using lithium-ion batteries that could ignite if struck by oncoming traffic.
- Typical protocols for assisting the occupant of a CAV like approaching the vehicle, finding the driver, and repair/towing will most likely have to be readapted to account for CAV's advanced design and technological capabilities.
- Motorist assistance by law enforcement and other entities may require specialized equipment, access to vehicle specific emergency protocols and additional training.

Introduction

Law enforcement responsibilities includes assisting a motorist with specific tasks. These can consist of help with repairs, contacting a towing agency and or family members, and waiting with and providing aid to the driver if they are in a dangerous situation. New vehicle problems may arise with CAV advancement and increase officers' current responsibilities that do not exist with standard vehicles. Law enforcement may need advanced training to provide aid to disabled CAVs. Furthermore, CAVs may vary in design between make and model, making additional training and access to vehicle specific information essential. Since many CAVs are electric, disabling these vehicles could be a high risk to the officer and the surrounding roadway and be more unpredictable as software advances.

Intelligence Reports

Terminology

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AV (Level 3 to 5) are designed to be self-driving in some situations and employ software and hardware technologies to provide capabilities ranging from advanced driver assistance to completely automated driving.

CAV is used where there is no distinction to be made in the discussion of traffic incident management between CV and AV technologies.

Potential Benefits

Table 1. Specific Vehicle Benefits

<table>
<tr><th>Opportunity</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Investigation Protocols</td><td colspan="2">• Vehicle data preservation
• Diagnostics and Feedback</td></tr>
</table>

Investigation Protocols

As roadway vehicles become more advanced in automation and connected abilities, vehicle malfunctions may be unfamiliar to drivers and emergency response personnel and potentially more complex. On the other hand, unlike standard vehicles, these vehicles may have the ability to preserve onboard data in the event of an accident or vehicle malfunction involving a CAV and may provide specific information to help investigators. This data will help determine culpability, whether the cause is an accident, vehicle malfunction, or another type of incident (TSAG, 2020). Detailed information may include the vehicle's mode at the time of the accident, the operator's engagement, potential software malfunctions and errors, and so forth. Additionally, it could be accessible in real-time to aid emergency responders in assisting the motorist.

Potential Challenges

Table 2. Specific Vehicle Challenges

<table>
<tr><th>Challenge</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Identifying CAV Operation Status</td><td colspan="2">• Ascertain the vehicle's operational mode, whether that be standby, currently operable, malfunctioning, or if the vehicle needs help</td></tr>
<tr><td>Disabling CAV Power Source</td><td colspan="2">• Electrical fire prevention knowledge and training
• Collaboration with manufacturers to provide guidance on disabling a CAV safely and obtaining design specifications and other documentation to enable vehicle stabilization</td></tr>
<tr><td>Identifying and Securing AV</td><td>• AV Identifier
• Detection Confirmation
• Operational Status
• Obtaining design specifications and other documentation to disable vehicle</td><td></td></tr>
<tr><td>Training</td><td colspan="2">• Training requirements and curriculum will need to be adapted to include CAVs in stabilization and extrication protocols</td></tr>
</table>

Challenge	Automated	Connected
Diverting Traffic	• Detection Accuracy to Traffic Control Devices • Executing appropriate response to traffic control devices	• Communication Mechanism

Identifying CAV and Operational Status

Different protocols may need to be executed, special tools utilized, and specific personnel with specialized expertise to handle such incidents and provide motorist assistance.

Disabling CAV Power Source

An integral step in in providing motorist assistance is stabilizing the CAV. Stabilization requires immobilizing the vehicle to prevent movement that creates an unsafe environment for responders, and avoid injury to the passenger (AVSC, 2020). With CAVs, stabilization may be a more complex process for responders if the vehicle is experiencing a software malfunction. They first may need to secure the area with barricades to prevent struck by incidents (Terry et al., 2018).

After securing the vehicle, disabling the CAVs power source becomes the next challenge. Many have mentioned that disabling the power source would be a high priority to prevent any hazardous scenarios (TSAG, 2020; Terry et al., 2018). It is unclear on what training or correspondence will occur between responders and CAV manufacturers regarding disabling the power source.

Training

Training requirements and curriculum will need to be adapted to include CAVs in stabilization, assistance and towing protocols. Fire and rescue personnel will need to understand what hazards could arise with these types of vehicles and acquire the proper skills to handle them (i.e., CAV power source, vehicle interior, software malfunctions, etc.).

Diverting Traffic

Often, securing an incident scene involves diverting traffic around the incident to prevent secondary accidents and keep emergency responders safe while tending the scene. Like move-over laws, emergency response personnel create visual cues to indicate to drivers to follow a specific path that may vary from the road's design and geometry. There is significant concern about how AVs will navigate around accident scenes and respond to temporary traffic signals and lane delineators such as message boards, flaggers, flares, cones, LEDs, or even law enforcement hand signals (Terry et al., 2018). It is uncertain if emergency response personnel will need to utilize new equipment or markings to improve communication with CAVs to navigate incident scenes safely.

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

Information	Definition	AV Impact	CV Impact
Precise Incident Location	A more precise location of where the incident took place (i.e., street names, mile markers, nearby interchanges, etc.)	AV and CV could provide precise location of incident to emergency response personnel and directions.	
AV Involvement*	Whether or not a CV and or AV was involved	Identifying an AV, specifically if involved in the accident, will be essential for emergency responder's safety. AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.	
Vehicle Information	Details relating to the vehicle(s) involved in the accident like damage sustained, orientation, location in the roadway, number of vehicles, etc.	AVs may require specialty equipment to move out of the roadway to prevent more damage or other hazards.	
Occupant Information	All information relating to occupants involved in the accident, including number of people involved, number injuries, severity of injuries, condition of occupants, etc.	Determine if AV has a driver/occupant.	

Information	Definition	AV Impact	CV Impact
Potential Hazards	Communicate details regarding active or potential hazards at the scene	CAVs may require emergency responders training to be adapted to account for other potential hazards that may arise that are exclusive to automated and connected vehicle technologies.	
Assistance Required	Communicate what assistance is needed and complexity of the situation		

** New Information Streams with CV/AV Implementation*

References

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VERIFYING AN INCIDENT AND DISSEMINATING INFORMATION

Problem Statement

It is unclear how communication between CAVs, emergency response personnel and traffic management centers coordinate. More specifically, additional challenges between CAVs and emergency responders emerge, such as:

- Once reported, the traffic incident must be verified before resources are deployed. Traffic management centers can aid in incident conformation and its location as well as location of patrolling officers.
- New communication methods must be established with CAVs so emergency personnel can identify them. Other design concerns emerge in messaging, such as the warning mode, frequency, lead-time, and feedback.
- Emergency response personnel overcoming gaps in training and knowledge to prepare for new risks posed by advanced vehicle technology like electrical fires or software errors.

Introduction

There are numerous information exchange capabilities for both CVs and AVs that may facilitate the verification of an incident and dissemination of incident information. CAVs may communicate the precise location of the incident to reduce travel times, confirm incident information prior to numerous response personnel arriving on the scene, assess risk factors, and help determine if additional resources are required to provide further aid. In addition to this, CVs may be able to move the information down the vehicle stream to help vehicles behind the incident to avoid the incident and perhaps reduce secondary incidents. Additional benefits and challenges of these applications are further outlined in the remaining sections of this report.

Intelligence Reports

Terminology

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CAV is used where there is no distinction to be made in the discussion of traffic incident management between CV and AV technologies.

Potential Benefits

Table 1. Specific Vehicle Benefits

Opportunity	Automated	Connected
Traffic Safety Alerts		• Emergency Vehicle Navigation • V2V Communication

Traffic Safety Alerts

Responding to incidents efficiently and effectively is crucial for public safety officials to maintain safety and health within their respective communities. This includes verifying an incident and disseminating critical information to road users and other emergency personnel as quickly as possible. By leveraging vehicle communication systems, connected vehicles may offer road users and other emergency responders traffic safety alerts to navigate around or to a roadway incident more efficiently. These communications may also provide additional dissemination capabilities by exchanging information with other vehicles for navigating purposes and confirming incident details.

Potential Challenges

Table 2. Specific Vehicle Challenges

<table>
<tr><th>Challenge</th><th>Automated</th><th>Connected</th></tr>
<tr><td>Identifying CAV and Operation Status</td><td colspan="2">• Ascertain the vehicle’s operational mode, whether that be standby, currently operable, malfunctioning, or if the vehicle needs help
• Potential Hazard Assessment</td></tr>
<tr><td rowspan="2">Information Dissemination</td><td>• AV Identifier
• Detection Confirmation</td><td>• Communication Mechanism
• Messaging Confirmation</td></tr>
<tr><td colspan="2">• Obtaining design specifications and other documentation to disable vehicle</td></tr>
<tr><td>Roadway Clearance</td><td colspan="2">• Specialty Equipment Requirements</td></tr>
</table>

Identifying CAV and Operational Status

Identifying whether a vehicle involved in an incident is a CAV can aid responding emergency responders. Suppose it is unclear whether the incident vehicle is a CAV. In that case, emergency responders may be unable to predict essential behaviors to maintain safety and unable prepare effectively while responding to a CAV incident. For example, deploying the necessary equipment, resources, and establishing communication with other communications. Emergency response personnel should also be able to determine the vehicle’s operational mode, whether that be standby, currently operable, malfunctioning, or if the vehicle needs help (Terry et al., 2018). However, this will mean the CAV must offer some visual marker to relay this information. Still, this information would be crucial in verifying incidents and deploying the necessary resources to respond.

Information Dissemination

Although vehicular communications could enhance incident verification and response, there is still work to be done to establish the actual communication mechanism with connected vehicles, emergency response personnel, or even traffic management centers. This line of communication must be reliable and rarely disseminate false information. Emergency responders and traffic management centers may still need to utilize traditional practices to confirm incident details and be able to override any inaccurate communications shared with responders and or other roadway users.

Roadway Clearance

Vehicles are usually moved from the roadway through tow trucks or response vehicles' push bumpers. Manufacturers will have to provide guidance on if specific towing and clearance procedures will be required of emergency responders whenever handling a CAV. It is unclear if towing practices used for standard vehicles will differ for CAVs. Additionally, whether specialized equipment will be required to handle these vehicles (TSAG, 2020).

Information Exchange Summary

Table 3. Information Exchange(s) and CV and AV Impact

<table>
<tr><th>Information</th><th>Definition</th><th>AV Impact</th><th>CV Impact</th></tr>
<tr><td>Precise Incident Location</td><td>A more precise location of where the incident took place (i.e., street names, mile markers, nearby interchanges, etc.)</td><td colspan="2">AV and CV could provide precise location of incident to emergency response personnel and directions.</td></tr>
<tr><td>Road Conditions and Optimal Route</td><td>Traffic and or Inclement Weather (personal knowledge, route provided by dispatch)</td><td colspan="2">Identifying an AV, specifically if involved in the accident, will be essential for emergency responder's safety. AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.</td></tr>
<tr><td>Incident information</td><td>Location, number of vehicles involved, number of people involved, severity of Incident, severity of injuries, urgency, any other details that may assist public safety officials</td><td colspan="2">AV and CV could provide knowledge of optimal route (local SME, GPS navigation)</td></tr>
</table>

Information	Definition	AV Impact	CV Impact
Knowledge of resources needed at the scene	Will yield various vehicles responding		
AV Involvement*	Whether or not a CV and or AV was involved	Identifying an AV, specifically if involved in the accident, will be essential for emergency responder's safety. AV accident involvement may require responders to approach and secure the vehicle differently than a standard vehicle especially if it is experiencing a software error that causes unwarranted movement.	
Vehicle Information	Details relating to the vehicle(s) involved in the accident like damage sustained, orientation, location in the roadway, number of vehicles, etc.	AVs may require specialty equipment to move out of the roadway to prevent more damage or other hazards.	
Need for Extraction	Whether or not occupant(s) will need to be extracted from vehicle	Specific expertise may need to be deployed if an occupant is trapped inside a CAV. Manufacturers may need to provide guidance to disable the vehicle safely to avoid further injury to the occupant or emergency response team.	
Potential Hazards	Communicate details regarding active or potential hazards at the scene	CAVs may require emergency responders training to be adapted to account for other potential hazards that may arise that are exclusive to automated and connected vehicle technologies.	

** New Information Streams with CV/AV Implementation*

References

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