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Literature Review Synthesizing the Current and Potential ATMA Applications

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16. Abstract

There are numerous applications of the Autonomous Maintenance Technology (AMT) that have yet to be fully utilized or widely shared. There are many slow-moving operations conducted by Departments of Transportation (DOTs) with an attenuator (e.g., work zone set up, operations, take down, repairs, mowing, sweeping), platooning of two or more vehicles either directly in-line or with lateral offsets (e.g., snow removal), and roadside infrastructure (e.g., sensors, data architecture) that supports maintenance operations; all of which could benefit from autonomous or smart technologies. Moreover, there has been significant momentum recently by research institutions, DOTs at various levels, and equipment manufacturers to develop autonomous transportation technologies. However, these efforts are often done in isolation of each other, and to best make use of the technology and applications available, it is crucial to fully evaluate and synthesize what technology has been and plans to be deployed. The objective of this research project was to review the literature and subject matter experts to identify (1) DOT operations that would qualify for AMT applications and (2) summarize applications of autonomous technology in maintenance operations that are occurring worldwide. These results show that: 1) autonomous technology in mobile and slow moving operations to date, although still preliminary, have targeted truck attenuators, traffic cone placement/retrieval, sweeping, mowing, pothole repair, and debris removal; 2) advancements have focused on using intelligent transportation systems (ITS), connected vehicles, and data management to create smart work zones, improve worker safety, and communicate to individual drivers through in-vehicle systems; and 3) automation of snowplows and road closures present as a near-term deployable solution.

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CDOT, Colorado, automation, autonomous, automated, smart work zone, ITS, slow moving operations, platooning, DOT, AMT Pooled Fund	This document is available on CDOT's website: https://www.codot.gov/programs/research

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Table of Contents

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Executive Summary

There are numerous applications of Autonomous Maintenance Technology (AMT) that have yet to be fully utilized or widely shared. There are many mobile and slow-moving operations performed by Departments of Transportation (DOTs) with or without an attenuator (e.g., work zone set up, operations, take down, striping, mowing, sweeping), platooning of two or more vehicles either directly in-line or with lateral offsets (e.g., snow removal), and roadside infrastructure that supports maintenance operations; all of which could benefit from autonomous technologies. Moreover, there has been significant momentum recently by research institutions, DOTs at various levels, and original equipment manufacturers to develop autonomous transportation technologies. However, these efforts are often done in isolation of each other, and to best make use of the technology and applications available, it is crucial to fully evaluate and synthesize what technology has been and plans to be deployed. The objective of this research project was to review the literature and subject matter experts to identify:

(1) DOT operations that would qualify for AMT applications.
(2) Summarize applications of autonomous technology in maintenance operations that are occurring worldwide.

The focus of this literature review was identifying publicly available sources online, with an emphasis on publications by cities, states, federal agencies, media, for-profit companies, academic publications, and journal articles. In total, there were 148 different references included in the document, with many more reviewed and excluded to do limited applied knowledge and/or weak topic match. The articles included span over the past 10 years, with a specific focus on literature published within the past five years (i.e., since 2019). This time period of focus allowed for recent and emerging technology trends and advancements to be highlighted.

The product of this research is provided in the supplemental Excel file, which is organized into 11 different tabs. The first tab provides a brief overview of the study, and the following ten tabs are divided into key themes related to AMT applications. The content in these tables include the source of the reference, a publication date, a summary of the key findings from the source, and a theme/subtheme for the article.

Mobile and Slow-Moving Operations (Table 1) contain a variety of literature most closely adjacent to the current AMT Pooled Fund applications (i.e., autonomous truck mounted attenuators (ATMAs) used as a crash cushion to protect workers in paint striping and sweeping operations). As such, this includes key press releases and overviews of the current ATMA focus, which serves to provide a recap of work to date from this Pooled Fund. Following these, is documentation on autonomous traffic cone deployment/retrieval trucks, autonomous sweeping vehicles, autonomous and remote mowers, and autonomous debris removal vehicles. This table details current technology available, which could be deployed to potentially improve efficiency, increase safety, decrease costs, alleviate workforce constraints, and reduce emissions.

Snow Operations (Table 2) is another similar application area as ATMAs, although the technology in this space appears more limited in capability at this point. Where autonomous snowplows have been predominately used in closed/controlled areas, such as airports, but have shown improvements in efficiency and platooning capabilities. While driver assistance technology and remote data collection/integration have been used in more DOT jurisdictions and applications.

Pavement Repair and Preventative Monitoring (Table 3) details work to date related to autonomous pothole repair, which still predominately require a human driver, but aim to remove the human worker needed outside of the protection of the vehicle. Further, connected vehicles for data collection and AI sensing and classification have made advancements in roadway inspection and asset management tasks.

Smart Work Zones (Table 4) contains a variety of advanced technology applications relevant to DOT operations. This includes automated speed enforcement, pavement markings to support AVs, automated flagging operations, traveler information displays, and data integration and warnings for queue detection and construction equipment.

Connected and Autonomous Vehicles (Table 5) provides further literature related to the potential that CAVs can offer in terms of improved safety and efficiency on highways. Such as delivering personalized information to drivers about wrong way driving, rerouting, incident response, and unintrusive data collection.

Traffic Incident Response (Table 6), although brief, provides recent advancements in incident management that leverage novel technology. This has largely focused on increased communication and connectivity to date.

Intelligent Transportation Systems (Table 7) focuses on infrastructure to support autonomous and intelligent DOT operations. This includes significant literature on infrastructure to support more efficient and safe intersections and automated flood warning systems.

Transit and Shuttles (Table 8) includes references on autonomous shuttle services and automated assistance for buses, with a focus on DOT sponsored projects. This table describes pilot programs, available technology, and lessons learned from implementation.

Unmanned Aerial Vehicles (Table 9) provides examples of autonomous drone operations conducted by DOTs, including improving communications, surveying, inspections, and emergency response.

Lastly, Framework and Legislation (Table 10) provides US DOT strategic/ comprehensive plans for deploying and operating automated vehicles, as well as legislation from various states related to autonomous vehicles.

Implementation Statement

These results synthesize current applications and future opportunities of autonomous maintenance technology (AMT) in one central location. The references detailing current standards of practice can serve as educational material to DOTs looking to adopt already tested and validated technology. Such technology includes autonomous truck mounted attenuators, traffic cone deployment/retrieval vehicles, and smart work zone ITS. The references detailing novel technology, in development or pilot operations, can be leveraged by DOTs and researchers that are interested in advancing the state of the industry through early technology adoption. Such technology includes autonomous sweepers, mowers, snowplows, pothole repair, shuttles, and connected vehicle communication.

Supplemental File

The literature review is organized in a supplemental Excel file which has also been printed to the following tables.

Title:	**Literature Review Synthesizing the Current and Potential ATMA Applications**

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Overview and Objectives:	There are numerous applications of the Autonomous Maintenance Technology (AMT) that have yet to be fully utilized or widely shared. There are many DOT slow moving operations with an attenuator (e.g., work zone set up, operations, take down; mowers; sweepers), platooning of two or more vehicles either directly in-line or with lateral offsets (e.g., snow removal), and roadside infrastructure that supports maintenance operations; all of which could benefit from autonomous technologies. Moreover, there has been significant momentum recently by research institutions, DOTs at various levels, and equipment manufacturers to develop autonomous transportation technologies. However, these efforts are often done in isolation of each other, and to best make use of the technology and applications available, it is crucial to fully evaluate and synthesize what technology has been and plans to be deployed. The objective of this research project is to review the literature and subject matter experts to identify *(1)* DOT operations that would qualify for AMT applications and *(2)* summarize applications of autonomous technology in maintenance operations that are occurring worldwide.

Methods:	The predominant focus of this literature review was finding sources available online, with an emphasis on publications by cities, states, federal agencies, media, for-profit companies, academic publications, and journal articles. This document is organized into ten key themes related to ATMA applications: *(1)* mobile & slow moving operations; *(2)* snow operations; *(3)* pavement repair and preventative monitoring; *(4)* smart work zones; *(5)* connected and autonomous vehicles; *(6)* traffic incident response; *(7)* intelligent transportation systems (ITS); *(8)* transit and shuttles; *(9)* unmanned aerial vehicles (UAVs); and *(10)* framework and legislation. The content included in these tables include the source of the reference, a publication date, a summary of the key findings from the source, and a theme/subtheme for the article. A summary of the key findings can also be found in the accompanying summary PDF.

Table 1: Mobile & Slow Moving Operations

Link	Source	Date Published	Notes	Subtopic
https://www.cbsnews.com/colorado/news/autonomous-truck-program-colorado-expand-grant-colorado-department-transportation/	Media	April 2023	Press release about CDOT's ATMA	Autonomous Truck Mounted Attenuator
https://www.codot.gov/news/2023/march/federal-grant-expands-automated-work-zone-program	Colorado DOT	March 2023	Press release of CDOTs SMART grant for expanding ATMA program.	Autonomous Truck Mounted Attenuator
https://aashtojournal.org/2023/02/10/study-self-driving-trucks-can-boost-work-zone-safety/	AASHTO	Feb 2023	Research post from University of Missouri + Missouri DOT regarding state interest in ATMAs. Namely, in a survey of 43 states, 19 are exploring ATMAs and 4 are pursuing. Also discusses benefits of ATMAs.	Autonomous Truck Mounted Attenuator
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-22-04-30-01.pdf	Caltrans	April 2022	Review of equipment and accessories for automating truck-mounted attenuator trucks. "This research succeeded in identifying, procuring, customizing, and demonstrating key shadow truck safety equipment technologies that increase highway safety by enhancing motorist responsiveness when encountering temporary highway work zones. The specific technologies deployed included an innovative radar speed feedback display sign capable of displaying the absolute speed of approaching vehicles while the truck and signboard are moving, video camera systems able to continuously record multiple views around the shadow truck, an automated highway work zone reporting system, and a shadow truck driver-activated panic/warning system. These innovative vehicle equipment accessories were combined into a safety Technology Package that can now be commercially purchased for installation on Caltrans TMA shadow trucks to improve safety in highway maintenance work zones."	Autonomous Truck Mounted Attenuator
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-21-12-31-03.pdf	Caltrans	Nov 2021	Overall evaluation in terms of safety and performance of an ATMA for Caltrans operations. "The ATMA will enable Caltrans to operate the TMA from the relative safety of the protected work truck. The ATMA leader/follower autonomous driving scheme was determined to be the simplest scheme by which to operate a shadow truck autonomously in a lane closure operation. Other popular competing autonomous driving schemes, such as remote control and selfdriving autonomous schemes, are complicated, expensive, and less practical. The ATMA successfully completed all safety and performance test scenarios. The next logical phase will be Caltrans deployment trials to determine how well the ATMA fits into maintenance operations in terms of functionality and operator training. Caltrans will need to obtain authorization to operate a heavy duty truck autonomously on the highway."	Autonomous Truck Mounted Attenuator
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/SWZ/AIPV_project_one_pager.pdf	National Work Zone Safety Information Clearinghouse	NA	One pager description of CDOT's ATMA	Autonomous Truck Mounted Attenuator
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/SWZ/ATMA_project_background-Kyle.pdf	National Work Zone Safety Information Clearinghouse	NA	Project background brief for CDOT's ATMA	Autonomous Truck Mounted Attenuator
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/SWZ/performance_evaluation-Joe.pdf	National Work Zone Safety Information Clearinghouse	NA	Performance evaluation brief for CDOT's ATMA	Autonomous Truck Mounted Attenuator
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/SWZ/TX-CWZ-peer-exchange_Virginia_DOT.pdf	National Work Zone Safety Information Clearinghouse	Oct 2018	Slidedeck on connected smart work zone efforts in Virginia, including a base station, smart vest, smart helmet, smart cone, and equipment unit.	Autonomous Truck Mounted Attenuator
https://aii.transportation.org/Pages/Autonomous-Truck-Mounted-Attenuator.aspx	AASHTO	NA	Overview of CDOTs ATMA. "In 2017, the Colorado Department of Transportation (CDOT) Division of Maintenance and Operations embarked on a program to remove the human operator from these TMA vehicles. The Autonomous Truck-Mounted Attenuator (ATMA) program at CDOT has retrofitted two TMA vehicles in their fleet with automated driving system technology. The vehicles are used to shadow the paint striping operation and the crews have logged over 100 miles and increasing every day in autonomous mode. The leader vehicle is a truck operated by a human driver and the follower or "trail" vehicle is the autonomous driverless truck mounted attenuator. The ATMA follows or replicates the leader's driving maneuvers. The leader vehicle is continuously transmitting highly accurate speed, position, and heading information to the follower so that the follower can replicate the leader's path while maintaining a specified gap distance (set by the human operator). Radar and other sensors on the front and side of the follower vehicle provide obstacle detection capabilities and may stop the follower vehicle if an object is detected in the vehicle's intended path. Emergency stop buttons in the lead vehicle provide a method to stop the follower, and push buttons on the exterior of the follower vehicle provide a method of stopping and shutting the vehicle down in case of emergency."	Autonomous Truck Mounted Attenuator

Link	Source	Date Published	Notes	Subtopic
https://www.traffic-safety-services.com/en/x-cone_traffic_cone_management_system.html	Traffic Safety Services	NA	Equipment manufacturer. Attachement for a vehicle. Automatic traffic cone deploy/pick-up attachement. Can put down and pick up cones to/from left or right. Can handle 6 cones per minute, spacing from 10 meters to any length.	Autonomous Traffic Cone Truck
https://arrowes.com.au/product/act-automated-cone-truck/	Arrowes	NA	Equipment manufacturer. From Australia. Automated cone truck. 400 cone capacity, deploy and retrieve, spacing 3m to 24m. Single driver operated. Truck requires driver, but has cameras and sensors to assist.	Autonomous Traffic Cone Truck
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-21-03-31-02.pdf	Caltrans	March 2021	Evaluation of an automated traffic cone machine (AutoCone trailer). Overall recommendation was not favorable of this design. Unable to retrieve cones while backing up and limited size and capacity. "Lane closure operations expose workers to physically demanding work and to traffic hazards. The AutoCone trailer was evaluated as a potential solution to reduce worker exposure and improve safety. The design has value for use by crews that place long closures regularly. It is recommended that the design be incorporated onto a truck and modified for use with the standard Caltrans 28-inch cone. The AutoCone 130 will potentially lower the risk of traffic exposure by reducing the number of operators to one and by keeping the operator in the safety of the vehicle's cab."	Autonomous Traffic Cone Truck
https://ahmct.ucdavis.edu/cone-machine-overview	UC Davis	NA	"The AHMCT machine places cones in the forward travel direction and retrieves them in either forward or reverse directions at speeds up to 10 mph. The machine is designed so that no on-site set-up is required, and both deployment and stowage of the mechanism is simple and fast. The entire operation is under control of the driver, who remains in the truck cab during both deployment and retrieval."	Autonomous Traffic Cone Truck
https://www.omegainfra.com/	Omega Infra	NA	"Omega Infra has developed: GERARD, to improve road worker safety and optimize efficiency. GERARD places the cones semi-automatically as a result of which the situation for the road worker becomes safer and physically less burdening. A simple modular system that makes it possible to be build into the cargo area of nearly every vehicle. GERARD is a device for efficient setting, placing and collecting traffic cones. GERARD can be built-in the cargo area of any flatbed pick up or truck. Final assembly of the Dutch traffic cone handler into the cargo area of vehicles is done by Omega Infra in De Lier, Holland. Or can be done by one of our dealers worldwide."	Autonomous Traffic Cone Truck
https://www.traffictechnologytoday.com/videos/video-automated-cone-laying-truck-shows-strong-results-in-trial.html	Media	June 2021	"In October last year, Australian road-safety technology provider Arrowes launched a new innovation called the Automated Cone Truck (ACT), the first commercially available truck in the world that automatically places and retrieves traffic cones."	Autonomous Traffic Cone Truck
https://x-cone.com/en/	X-Cone	NA	"X-Cone is a fully automated traffic cone management system offering a higher level of safety for workers and maximum efficiency for contractors. By using the illuminated touchscreen control the driver can select the desiered cone spacing which can be from 10 meters to open end. Once this is set X-Cone can deploy as well as collect traffic cones fully automatic. X-Cone operates multidirectional. The machine can deploy/ collect traffic cones from either right- or left hand side, as well as in and against traffic flow direction. Because of the multiderictional design the machine can be used for any job."	Autonomous Traffic Cone Truck
https://nationalhighways.co.uk/suppliers/second-automated-cone-laying-vehicle-unveiled/	National Highways UK	June 2021	"Highways England has today released footage of a second automated cone laying vehicle designed to protect roadworkers which is now undergoing off-road trials in the UK. Two automated vehicles have been developed as part of that vision. The first, developed by Highways Care, has completed its on-road trials and can now be taken out to the marketplace for use on the strategic road network. And now the second vehicle, developed by King Highway Products, has been unveiled as it carries out extensive off-road testing at Manston Airport in Kent. This vehicle is quite different because King has opted for more of a 'revolver' style deployment with a huge rotating drum putting out and collecting the cones. Currently, putting out cones is undertaken by two people on the rear of a vehicle working in tandem. Usually working at night and in all weathers, the workers lift up to six tonnes in cones alone per shift. Cones are vital to protect road users and road workers when essential work is being carried out but with motorway traffic thundering past, the job can be quite scary. The automated vehicles will improve safety and free up two workers for other tasks."	Autonomous Traffic Cone Truck
https://bigbuild.vic.gov.au/news/victorias-big-build/automated-traffic-cone-truck-a-safety-innovation-on-our-projects	Media	Jan 2023	Updated news article about the Arrowes Automated Cone Truck, including a video of it in action.	Autonomous Traffic Cone Truck
https://www.enway.ai/	Enway	NA	Available product from manufacturer. Autonomous municpal sweeping. Driverless operations with remote operator service as needed. Case study results available from Singapore.	Autonomous Sweeping

Link	Source	Date Published	Notes	Subtopic
https://www.boschung.com/na-en/product/urban-sweeper-s2-0-autonomous/	Boschung	NA	Available product from manufacturer."Proven performance, powered by Electric, the Urban-Sweeper S2.0 is now autonomous, driven by WIBOT a high-tech autonomous company. Equipped with a combination of lidars, cameras, mm-waves radars and gnss antennas, the Urban-Sweeper S2.0 Autonomous has a 360° coverage of its surrounding environment. The driverless street sweeper can not only be used in closed areas, it can safely sweep the public streets with a level 5 certification. The low noise pollution of the electric sweepers enables a 24h use. The accurate and efficient recognition algorithm allows the sweeper to track all objects in sight simultaneously, leaving no chance to dirt. Switch to manual mode and drive the Urban-Sweeper S2.0."	Autonomous Sweeping
https://trombia.com/free/	Trombia	NA	Available product from manufacturer."Trombia Free is the world's first full power, electric and autonomous street sweeper. Trombia Free delivers up to 10 times faster area cleaning, but uses only 15% of the energy required for advanced high performance sweeping."	Autonomous Sweeping
https://www.buchermunicipal.com/us/en/news/autonomous-sweeper-0	Bucher Municipal	NA	Available product from manufacturer. "Autonomous sweeper approved for public road use in Singapore Bucher Municipal's first all-electric compact sweeper CityCat 2020ev became autonomous. In collaboration with Enway, the Berlin software manufacturer of self-driving utility vehicles, a major milestone has been achieved with the approval of the autonomous sweeper for public road use in Singapore. This is a step forward to Singapore's efforts for a more sustainable city. Since 2017, Bucher Municipal has been in cooperation with ENWAY to actively promote and further develop sustainability in the municipal sector. The autonomous sweeper "Donner" is based on the all-electric model CityCat 2020ev and was equipped with the technology for autonomous operation of ENWAY. For the use on public roads in Singapore further adjustments were necessary by the team in cooperation with different parties. The first milestone has already been reached: the fully autonomous compact sweeper "Donner" has taken and passed the Land Transport Authority's test for autonomous vehicles and officially receives approval for public road use in Singapore."	Autonomous Sweeping
https://www.northjersey.com/story/news/transportation/2023/05/22/port-authority-ny-nj-testing-autonomous-street-sweepers/70170495007/	Media	May 2023	Port Authority of New Jersey piloting the Finland-based Trombia autonomous sweeper.	Autonomous Sweeping
https://blogs.nvidia.com/blog/2022/05/13/weride-autonomous-street-sweepers/	NVIDIA	May 2022	Fleet of 50 autonomous sweepers operating in Guangzhou, China. Run off a cloud-based platform that automatically schedules and dispatches vehicles, all without needing a human driver.	Autonomous Sweeping
https://www.intelligentliving.co/trombia-free-autonomous-street-sweeper/	Media	May 2021	"In September 2020, Finnish road maintenance technology developer Trombia Technologies debuted the world's first full-power electric autonomous street sweeper. It took to the streets of Helsinki as part of the Jätkäsaari Mobility Lab unveiling. Since then, the robot has been cleaning the Helsinki Baana bicycle lane during the day, street cleansing elsewhere within the city by night. Its job is to gradually move through city streets, cleaning dust, dirt, and debris as it goes. It can go 10 km/h but is restricted to a pace of between 2 to 6 km/h (1.2-3.7 mph). It can sweep the roads for approximately 17 hours per charge of its Li-ion batteries."	Autonomous Sweeping
https://www.robotics247.com/article/trombia_pilot_shows_autonomous_sweeper_improves_maintenance_operation_efficiency	Media	Nov 2021	"Trombia worked with facility management operator ISS Finland for the pilot at Helsinki Airport in July. The company reported the following findings: - Zero safety incidents - Low noise levels, even around the autonomous sweeper - Effective cleaning results across the entire working area, both indoors and outdoors - Year-round usage possible with waterless air-knife technology - Cost efficiency that will improve even more with planned remote operator centers - 30 tons less CO2 emissions with every sweeper."	Autonomous Sweeping
https://www.imeche.org/news/news-article/trombia-gives-street-sweepers-the-autonomous-treatment	Media	July 2021	"The project's main target, however, is energy efficiency. The firm claims its sweeping technology uses 85% less energy and 95% less water than conventional suction sweeper technology, and it can reportedly save 32.5kg of CO2 emissions per 1,000m2 cleaned compared to diesel-fuelled alternatives. "The only way to combat the over 3m CO2 tonnes that street sweepers around the world cause is to change to a greener and more power-efficient option," Trombia claims. The company's pilot programme targets ports, car parks and 'smart city' projects, so it could be a while before we see the sweeper on the winding and irregular paths of patchwork cities like London."	Autonomous Sweeping
https://www.electronicdesign.com/markets/automotive/article/21808337/autonomous-sweepers-keep-roads-clean-in-major-chinese-cities	Media	July 2019	"In China, the Idriverplus street cleaning vehicle is an unmanned, purely electric solution to intelligently sweeping roads.The Chinese firm's road sweeper, known as "Viggo," automatically tracks and avoids obstacles as it cleans. More than 100 units are now in operation at universities, factories, parks, an amusement park, and city streets—with deployments in Beijing, Tianjin, Shanghai, Hebei, Zhejiang, Henan, Hunan, and other provinces and cities in China. Idriverplus also has strategic cooperation partnerships in Singapore, Dubai, Malaysia, and other areas in Asia."	Autonomous Sweeping
https://www.carscoops.com/2022/05/the-robosweeper-is-an-autonomous-ev-truck-designed-to-clean-and-sanitize-public-roads/	Media	May 2022	China deploying Robosweeper, an autonomous EV truck by WeRide for cleaning and sanitizing public roads. Vehicle looks like a bus, equipped with Level 4 autonomy, with no driver on-board. Uses tinted windows to hide the fact that there is no human inside.	Autonomous Sweeping

Link	Source	Date Published	Notes	Subtopic
https://www.therobotreport.com/trombia-free-autonomous-street-sweeper-launched/	Media	Sept 2020	"Trombia Technologies said its new system is the world's first street-cleaning device designed to be operated fully autonomously in all weather conditions in modern smart cities and industrial destinations. Trombia Free is equipped with an autonomous, lidar-based, machine vision technology that filters the signal "noise" from rainy, snowy, or other environments. The company said it has developed advanced algorithms to absorb data on objects from various sources and to generate millions of illustrations of an object at once. This enables accurate and safe localization, it said."	Autonomous Sweeping
https://www.witpress.com/elibrary/tdi-volumes/6/1/2862	Peer Reviewed Journal	2022	"The objective of this research was to evaluate the potential of autonomous and connected sweepers for cleaning pavements and cycle ways. Supported by sustainable policies, the networks of cycle ways are growing considerably outside cities, and their maintenance is demanding in terms of economic resources. The current study examines the idea of replacing manned service vehicles by autonomous sweepers in urban areas. Autonomous sweepers could be operated from a control room to perform planned and on-demand cleaning tasks. Tests were carried out with the S100N Spring developed by the Chinese company Idriverplus Technology Co., Ltd. The sweeper performance and efficiency have been evaluated (1) with gravel, leaves, pine cones and rubbish in a closed test area and (2) in real conditions, on two pavements in Kongsberg (Norway). The results from the cleaning tests and the interactions. The field experiments showed a real potential for replacing manned service vehicles in urban areas. In the manual mode, they provided satisfactory results: the sweeper collected gravel and sand with an efficiency from 80.8% to 98.2%. We recommend using the lowspeed mode with wet sweeping to avoid the dust flying into the air and being deposited on sensors and cameras. Some design changes are required to avoid leaving too much gravel on the ground. The sweeper could sweep the same area several times, but this could create unnecessary noise levels for the population. Concerning the collection of natural materials and rubbish, the tests confirmed that large items are difficult for the sweeper to pick up. However, it collected leaves, cones and twigs with no major difficulty. We recommend avoiding the sweeper sweeping areas with large numbers of pine cones or long twigs. In addition, the safety function in manual mode may confuse the operator, who may expect the sweeper to stop in particular situations. A better user-friendly interface should be also developed on the sweeper, and clear messages should be sent to the operator. The field experiments in the autonomous mode provided insights into the limitations of the sweeper for performing equivalent cleaning tasks of a manned service vehicle. The sweeper cleaned the pedestrian street and the pavements with great satisfaction. However, we recommend investigating further challenges related to the interactions with the vulnerable road users. A better solution must be found for ensuring safety and for avoiding disturbing the pedestrians' and cyclists' movement on pavements. For example, better warning systems, headlights and voice messages may contribute to ensuring that vulnerable road users anticipate where the sweeper is going to move and what it is waiting for."	Autonomous Sweeping
https://doi.org/10.3390/su13168867	Peer Reviewed Journal	2021	Study at Purdue airport using an automated mower, size 4ft by 4ft. Study discusses using a fleet of automated mowers as well. "Experience at the Purdue Airport (KLAF) suggests that automated mowing may support economic and environmental aspects of sustainability. Automated mowing supports economic efficiency by reducing personnel requirements, although personnel are still needed for inspections, maintenance, and "mower rescue" if there is a malfunction (technical or field issue). Automated mowing supports environmental impacts by reducing local emissions since the mower is powered by electricity rather than gasoline; this benefit would be increased with the use of solarpowered mowers. Automated mowing may not be viable everywhere, and factors such as terrain, access to available power, acreage, and location on the airfield (including proximity to protected areas) must be carefully considered. Although automated mowing will not completely replace traditional mowing in the near future, autonomous mowers in remote areas may be an appropriate practice to support airport sustainability"	Autonomous Mower
https://dot.la/graze-lawnmower-robot-2657066498.html?utm_campaign=post-teaser&utm_content=sv9mo3h9	Media	Mar 2022	"Graze, a Santa Monica-based startup looking to change the landscaping industry by building electric, autonomous lawn mowers. On Tuesday at the Glendale Sports Complex, Glendale Mayor Paula Devine announced that the city will be the first in Los Angeles County to join Graze's pilot program, allowing Glendale facilities like Sports Complex to its equipment. A Graze mower consists of two large sections. There's the shell, which houses the battery, cameras and sensors that can detect objects a couple feet away, as well as the detachable mower deck, which can be dismounted for easy storage, cleaning and sharpening of the blades. Vlay boasted that the detachable mower deck was built with future attachments in mind, such as a leaf blower or golf ball picker."	Autonomous Mower
https://www.equipmentworld.com/roadbuilding/article/14963565/i-robot-dot-contractor-now-cutting-interstate-grass-with-robotic-lawnmowers-photos	Media	April 2015	"DOT contractor now cutting Interstate grass with robotic lawnmowers. But these mowers are remote-controlled and that's been a business boon for Dixie Lawn Service, according to a report from WCNC TV. The company has begun deploying the robots for highway detail contracts maintaining interstates with contracts from both the North and South Carolina departments of transportation. We've taken our crews of say six crew members and we've cut them down to two," Dixie Lawn Service's Jimmy McHenry said. "Before we've had to put people with hand type equipment with a weedeater or a chainsaw and they'll have to climb up the slope and cut that debris. The mowers, which cost between $75,000 and $80,000, are operated remotely up to 1,000 feet away, which keeps workers out of danger on steep inclines. And the mowers are keeping the crews safe in the hot summer months. The robotic lawnmowers have increased Dixie Lawn Service's efficiency by 25 percent and cut labor costs in half."	Autonomous Mower
https://www.grazemowing.com/	Graze	NA	Commercial grade autonomous mower. Marketed for road + highway medians, municipaltities, solar fields, parks & rec, airports, and golf courses.	Autonomous Mower

Link	Source	Date Published	Notes	Subtopic
https://www.therobotreport.com/how-graze-mowings-self-driving-mower-is-disrupting-the-100-billion-commercial-landscaping-industry/	Media	June 2021	"Graze currently manufactures the world's only commercial-size autonomous mower.Each Graze mower can be controlled from a computer, tablet or smartphone. With the push of a button, the mower navigates around the boundaries of the area it will service, tracing the borders and interior in a series of parallel paths. One initial run is all it requires for the mower to map the space and take note of all obstacles, like trees and bushes. From then on, it will automatically mow that same area at the push of a button. Graze has already developed a second-generation mower—equipped with laser imaging, detection and ranging (LIDAR), which enables it to spot and avoid smaller and/or faster-moving objects. The Graze V-2 also comes with a 7-hour battery system as well as a customizable mow deck, which can be fitted with specialized attachments for trimming, edging, snow blowing, mulching and more."	Autonomous Mower
https://www.actsoft.com/2020/02/07/how-will-autonomous-mowers-affect-your-landscaping-company/	Media	2020	"Earlier this year, Arkansas State University announced that, in an effort to reduce expenses and cut back on fuel use, it introduced autonomous electric mowers to supplement its larger fleet of maintenance equipment. These one-foot-wide mowers are able to help maintain campus grounds without much need for human interaction. In addition to the savings, relying on this equipment also reduces noise and air pollution on campus. The technology uses GPS to maintain a designated tract of land and can run for up to 4.5 hours on a single charge. That's when a human element is needed, of course: when it's time to charge the units. After an hour of charging, they're good to go again. The best part? After the initial investment, these mowers only cost between $10–50 per season to operate."	Autonomous Mower
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-19-09-30-05.pdf	Caltrans	Oct 2019	"This report presents results for research evaluating remote control mowers for roadside management. Caltrans is interested in this technology as a potentially new approach for mowing steep slopes where tractor-based mowing is too hazardous or otherwise unfeasible. Commercially available remote control mowers show great promise for safely and efficiently managing vegetation on steep slopes and in constrained areas. This research evaluated the applicability of remote control mower systems for Caltrans operations. This evaluation includes two seasons of field testing with Caltrans operators, including operators' feedback on their experiences with the systems. Using an RCM to mow the steep, sloped area of the average interchange will increase the associated mowing cost of mowing an interchange by approximately 30%. However, regular use of an RCM to mow slopes will reduce tip-over accidents. Mowing the steepest slopes cannot be done with CMs, and operators may be tempted to mow at the limits of the CM. If RCMs are used regularly, the CM operators will be less likely to operate at the limits of the CM. This will reduce tip-over accidents, which will reduce injuries and costs. It is recommended that the deployment of an RCM with Caltrans crews be continued. Additional models are becoming available and costs are expected to be lowered."	Autonomous Mower
https://www.equipmentworld.com/roadbuilding/video/14970125/missouri-dot-makes-device-just-for-clearing-road-debris	Media	Oct 2018	Missouri DOT system called JAWS (Julie's Automated Waste-Removal System), which is mounted to the front of a pickup and operated remotely from inside the truck, so workers don't have to enter the road to remove debris. "JAWS is an automated drop-down skid plate that can scoop up debris and move it to the shoulder out of traffic, where it can be handled more safely. The operator uses a remote hand control to operate it. A mounted camera gives the operator visibility. Along with being safer, the device saves money by requiring fewer workers and vehicles in removing debris, according to the agency."	Autonomous Debris Removal

Table 2: Snow Operations

Link	Source	Date Published	Notes	Subtopic
https://www.key.aero/article/how-oslo-airports-autonomous-snow-removal-tech-works	Media	Dec 2022	Oslo airport using driverless snow plows. 38ft wide snowplough with maximum plowing sped of 40mph, clearing capacity of 5,253,000 sq ft per hour. Can handle 6 machines deployed at once with only one operator.	Autonomous Snow Plow
https://www.roboticsbusinessreview.com/unmanned/autonomous-snowplow-shows-promise-safety-speedbump/	Media	April 2018	Companies Yeti Snow Technology, Semcon, and Overaasen. Two autonomous slowplows at Fagerness Airport in Norway. The Yetis follow a pre-programmed route, working together. 18.3 feet wide, cleared an area of 357,500 square meters per hour.	Autonomous Snow Plow
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0016936-ca16-2167-finalreport.pdf	Caltrans	Aug 2015	Describes system install, setup, testing, and performance for a GPS snowplow driver assistance system. Developed by University of Minnesota, tested by Alaska Department of Transportation, and then implemented by Caltrans. “Snowplow DAS functions include lane position indication, lane departure warning, and forward collision warning. Lane position indication and lane departure warning are displayed on a HUD and Collision Warning System (CWS) uses a millimeter-wave radar which performs well in the snow environment as it detects vehicles and other inorganic objects. Also includes haptic feedback seat system using vibrating motors. Azimuth angle data allows the system to map detected obstacles to their lateral location, i.e. the system can show the driver what lane the obstacle is located in relative to the snowplow. The system also stores the location of fixed roadside objects in a geospatial database to eliminate false negative collision warnings. Highly accurate vehicle position is provided by the RTK GPS receiver, which can deliver sub-centimeter accuracy under fairly ideal conditions. However, its accuracy is generally recognized to be only centimeter-level under normal operating conditions. Producing a high-accuracy RTK GPS solution requires data from two dual-frequency (L1 and L2) GPS receivers—one stationary base station and one rover—collecting signals from at least five GPS satellites at the same time. The solution can be calculated in real-time by the rover GPS (on the snowplow) when it receives the base station data in real-time through a cellular radio data link.” “The DAS radar unit experienced icing during heavy snow storms. Significant effort and time was spent in developing and testing radar icing mitigation solutions. A viable solution was developed and tested near the end of the research. Due to the lack of snow storms in the research period, and the time spent developing radar icing mitigation solutions, more time is required for testing and evaluation to completely establish whether the DAS would be an effective tool to reduce snowplow operator’s exposure to collision and road departure risks in the poor visibility conditions encountered in California, and, if effective, in what ways the system can be adopted by Caltrans.”	Autonomous Snow Plow
https://mail.autosnowplow.com/welcome.html	University	2023	ION Autonomous Snowplow Competetion. Annual competition among universities to design, build, and operate a fully autonomous snowplow.	Autonomous Snow Plow
https://roboticsandautomationnews.com/2021/04/09/avinor-ploughs-e40-million-into-yeti-autonomous-snow-removal-vehicles-at-norwegian-airports/42173/	Media	April 2021	Norwegian aiport operator Avinor purchased Yeti Move autonomous slow plows. Plows claim to be more cost efficient, higher capacity and greater clearing width, making it possible to reduce the number of vehicles and thereby achieve major environmental benefits.	Autonomous Snow Plow
https://semcon.com/yeti/	Semcon	NA	Equipment manufacturer. Autonomous snow plows. First official test in March 2018. Company in Norway, currently used at airports.	Autonomous Snow Plow
https://www.constructionequipmentguide.com/new-snowplow-technology-targets-efficiency-safety/54544	Media	Nov 2021	Integration of data to improve snow plow operations and efficiency. "Arizona DOT deployed 25 high-tech snowplow trucks just before the pandemic, taking advantage of precision control and computerized weather data and pavement temperatures to clear snow and ice on roadways. This January, Minnesota DOT began testing a snowplow-based digital messaging system that would allow plow operators to activate digital highway signs, warning motorists of slow-moving vehicles on the road." "Robotics, artificial intelligence and autonomous vehicles are all alternatives being explored in the snow and ice management arena. The Toro Company recently acquired Left Hand Robotics Inc., a Colorado-based firm known for developing innovative autonomous solutions for snow management, to strengthen its leadership in next-gen technologies such as autonomous, smart connected and alternative solutions. In fact, Left Hand Robotics' RT-1000, an autonomous snow-clearing and ice-control robot, was added by the city of Grand Prairie in Alberta, Canada, to its fleet to use on the city's network of trails."	Autonomous Snow Plow
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-16-11-23-01.pdf	Caltrans	Dec 2016	Evaluation of University of Minnesota's GPS Snowplow Driver Assistance System. Ultimate recommendation: "The system as delivered at the outset of the project cannot meet Caltrans’ needs for a snowplow DAS. The radar is rendered unreliable by the snow and ice buildup. The radar enclosure delamination introduces additional system reliability concerns. Without a reliable radar to provide collision warning, no component of the DAS can be used in whiteout conditions. Use of the DAS lane-keeping component without collision warning is not a suitable use of the system and is not recommended."	Autonomous Snow Plow

Link	Source	Date Published	Notes	Subtopic
https://www.truckinginfo.com/329914/how-alaska-dot-uses-gps-for-precision-plowing	Media	April 2019	Driver assistance system in snow plows in Alaska, using a GPS system to render a virtual image of the road in the cab. "In the cab, drivers have a display that shows the truck's position relative to the lane markings on a moving map. The center-line appears as a yellow dashed line, while the outer lane markings appear as solid white lines. If the truck travels over the lane marking, a solid red line appears warning the driver he or she is crossing out of the prescribed lane. In addition to the in-cab display, there are motorized vibrators in the driver's seat that activate if the truck crosses out of the lane. If they cross over the center line -- drifting left -- a vibrator in the left side of the seat goes off. Drift to the right toward the shoulder, and the right-side vibrator goes off. It's a natural human reaction to move away from something you don't expect, so almost subconsciously the driver steers away from the source of the vibration, thus centering the truck in the lane. The displays are of such resolution that drivers, with a little practice, can steer the plows along the winding roadway using just the image on the display. As well as the GPS, the plows are equipped with forward-looking radar to warn of objects in the road, such as abandoned cars."	Autonomous Snow Plow
https://winnipeg.ctvnews.ca/autonomous-snowplow-makes-debut-on-winnipeg-runway-1.4336891#:~:text=The%20future%20has%20arrived%20at,its%20kind%20in%20North%20America.	Media	March 2019	Autonomous snowplow used to clear runways in Winnipeg. Otto manufacturer Northstar Robotics. Uses GPS to guide the vehicle, allowing it to operate in zero visibility conditions.	Autonomous Snow Plow
https://intrans.iastate.edu/app/uploads/2018/03/SnowplowReport.pdf	Midwest Transportation Consortium	Oct 2002	Geographic information systems (GIS) and artificial intelligence (AI) techniques were used to develop an intelligent snow removal asset management system (SRAMS). The system has been evaluated through a case study examining snow removal from the roads in Black Hawk County, Iowa, for which the Iowa Department of Transportation (Iowa DOT) is responsible. The SRAMS is comprised of an expert system that contains the logical rules and expertise of the Iowa DOT's snow removal experts in Black Hawk County, and a geographic information system to access and manage road data. The system is implemented on a mid-range PC by integrating MapObjects 2.1 (a GIS package), Visual Rule Studio 2.2 (an AI shell), and Visual Basic 6.0 (a programming tool). The system could efficiently be used to generate prioritized snowplowing routes in visual format, to optimize the allocation of assets for plowing, and to track materials (e.g., salt and sand). A test of the system reveals an improvement in snowplowing time by 1.9 percent for moderate snowfall and 9.7 percent for snowstorm conditions over the current manual system.	Planning / Management
https://www.transportationmatters.iowadot.gov/2015/01/do-you-see-what-i-see-iowa-dots-track-a-plow-website-a-hit-with-travelers.html	Media	Jan 2015	Press release / overview of Iowa DOT snow plow tracking website, so anyone with internet access can see realtime info on where snow plows are/have been and video footage from plows.	Planning / Management
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-22-03-31-01.pdf	Caltrans	May 2022	Discusses improvements to hopper body and tailgate sanders for winter road maintenance. Discusses future opportunities and importnace of automating to maintain a constant speed for improved performance and efficiency.	De-Icing
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-21-11-30-01.pdf	Caltrans	Nov 2021	"This report documents implementation and training for the Mountain Pass Road Opening (MPRO) Driver Assistance System, including deployment of eight systems to four California Department of Transportation (Caltrans) yards. Caltrans has eight mountain passes that are closed each fall and reopened each spring. Opening these passes is a difficult job with few visual indicators or landmarks to guide experienced snowplow operators. Existing techniques, such as probing the snowpack with poles, path staking, and active embedded cable systems, have associated drawbacks. The MPRO system uses an infrastructure-free approach that uses the Global Navigation Satellite System to provide a real-time in-cab mountain pass road opening system for rotary plow driver assistance. The system was developed in previous research to be portable, easy to install, and sharable across multiple vehicles. The AHMCT Research Center developed a field-ready and deployable GPSbased mountain pass road-opening rotary plow DAS to guide rotary plow operators to drive and stay over the roadway during road opening operations. Primary system objectives are increased safety and snow-removal efficiency with minimal capital investment and decreased environmental impact and costs associated with infrastructure repair. The system was developed to be portable and easily installed with a small number of units sharable across statewide mountain pass opening operations."	Planning / Management
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-17-02-28-01.pdf	Caltrans	March 2017	Summary of a two-day workshop on implementing Automated Vehicle Location technology for winter maintenance applications, such as with data from other sensors on weather and pavement temperature. Workshop included presentations from 11 different agencies that implement AVL technology.	Planning / Management
https://enterprise.prog.org/wp-content/uploads/ENT-P7-Winter-Road-Cond-Phase-2-Report-FINAL-092520.pdf	ENTERPRISE Pooled Fund	Sept 2020	"The process of gathering information about road conditions during a winter storm typically involves plow operators, enforcement or other traffic operations staff reporting on conditions that they observe while on the road. ENTERPRISE sponsored this effort to research what transportation agencies are doing to leverage technology and automate or assist with winter road condition reporting. Phase 1 of the effort focused on gathering information about how agencies were approaching automated and assisted classification of road conditions. This report concludes Phase 2 which has explored specific attributes of data that can be used to automate road condition reporting with the intent of increasing agencies' understanding and evaluation of this data. This was achieved by establishing a list of available data sources, providing an overview of the types of data available from each source, describing common characteristics for various types of data, and gathering information about agency experiences with data to automate the reporting of winter road conditions."	Planning / Management

Link	Source	Date Published	Notes	Subtopic
https://www.codot.gov/news/2016-news-releases/02-2016/cdot-announces-new-snow-plow-monitoring-system	Colorado DOT	Jan 2016	Automated Vehicle Locator system tracks snow plows and provides near real-time location information of snow plows online for the public to see.	Tracking

Table 3: Pavement Repair and Preventative Monitoring

Link	Source	Date Published	Notes	Subtopic
https://www.thedrive.com/tech/21701/english-researchers-develop-pothole-repair-drone-using-mounted-3d-printer	Media	June 2018	Researchers at University of Leeds and University College of London created a UAV (drone) that scans for potholes, then lands above the pothole and perfroms the asphalt repair.	Autonomous Pothole Repair
https://spectrum.ieee.org/sick-tim10k-challenge	Media	May 2022	Researchers developed hardware and software to use LiDAR + GPS to scan roadway surfaces and identify areas in need of repair. Device can be attached to any vehicle.	Autonomous Pothole Repair
https://www.thedrive.com/news/38805/jcbs-new-all-in-one-roadwork-machine-fixes-potholes-in-under-10-minutes	Media	Jan 2021	Manufacturer JCB's Pothole Pro requires a human driver, but otherwise streamlines the process, not requirig external workers to assist. Can repair potholes in as little was 8 minutes.	Autonomous Pothole Repair
https://www.constructionenquirer.com/2021/01/11/new-pothole-machine-delivers-road-repairs-four-times-faster/	Media	2021	Manufacturer JCB's Pothole Pro. Has automated planner, cutting tool, and sweep bucket. Travel speed of 40 km/hr. Claims to cut costs by 50% by mechanizing job.	Autonomous Pothole Repair
https://www.electronicwings.com/users/VipulYadav/projects/667/pothole-patching-robot-for-road-maintenance-automation	Media	Sept 2020	Pothole patching robot. "A semi-autonomous system that can be wirelessly controlled by a single person for doing the road maintenance work, more specifically for patching potholes that need emergency maintenance more frequently to keep the traffic moving and avoid any accidents caused by bad condition of roads."	Autonomous Pothole Repair
https://www.pcworld.com/article/465563/georgia_techs_automated_road_repair_system_fills_in_pesky_cracks.html	Media	June 2012	Researchers at Georgia Tech developed an automated road repair system, which hitches to a truck, and that can detect and fill in cracks in the asphalt. System first detects cracks using a stereoscopic camera, produces a crack map within 100 milliseconds, then uses a series of 12 nozzles to spray a sealant solution to fill in the crack. System operates at a maximum speed of 3 miles per hour. Only requires a driver to drive the truck it is attached to.	Autonomous Pothole Repair
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/research-results/task1738-rrs-3-13-a11y.pdf	Caltrans	March 2013	"After two Caltrans maintenance workers were killed while patching highway potholes, Caltrans moved to evaluate and deploy innovative automated equipment to reduce worker exposure when conducting highway patching operations." In collaboration with UC Davis, developed a pothole patcher that only requires a human in the driver seat, not on the road.	Autonomous Pothole Repair
https://globalnews.ca/news/4247917/canadian-pothole-machine/	Media	June 2018	"A made-in-Canada solution promises to patch potholes in less than two minutes, doesn't require long stretches of road closures, and keeps the road crew member in the safety of an air-conditioned cab. This machine does everything that that crew you were talking about does, and it does it with one person. It cleans out the pothole, it sprays it with an adhesive, it fills it with asphalt, and, most important, it compacts it and makes a permanent patch."	Autonomous Pothole Repair
https://insights.globalspec.com/article/15281/university-of-liverpool-spinoff-to-automate-road-maintenance	Media	Oct 2020	Robotiz3d, a company in the UK, using a combination of robotics and AI to locate road defects and repair potholes and cracks in the pavement. AI autonomously detects cracks before they turn into potholes, and fills the cracks autonomously. Can also predict future severity of cracks and potholes.	Autonomous Pothole Repair
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-20-04-30-01.pdf	Caltrans	April 2020	"This report provides summary details of integrating monochrome and Thermal Infrared (IR) imaging cameras, 3D Ground Penetrating Radar (3D-GPR), and Global Navigation Satellite System (GNSS)/Inertial Navigation System (INS) systems into a multi-sensing vehicle for highspeed collection of pavement condition data for use in Nondestructive Testing (NDT)."	Pavement Condition
https://www.maintain-ai.com/post/automated-road-damage-detection	Maintain-AI	NA	Machine learning and AI tool for pavement defect detection in a more efficient and reliable way. Claims to just require data collection through an iPhone, uploaded to their system. "Traditional methods of manual inspection and road asset management are time-consuming, labour-intensive and often lead to inconsistencies in data collection. As an alternative, laser road scanning vehicles are expensive to buy or lease which restricts their use and therefore delivers results far too infrequently to accurately assess the condition state of road assets and help decision-makers manage them. This is where Maintain-AI's technology comes in. Our cutting-edge automated road damage detection approach that uses computer vision offers a multitude of advantages over traditional methods and even other automated systems currently on the market, able to detect, record and report on many defect types. We aim to be leaders in supporting Artificial Intelligence Road Maintenance."	AI for Road Damage Detection
https://venturebeat.com/technology/eyevi-looks-to-improve-road-maintenance-with-digital-twins/	Media	Feb 2022	EyeVi, an Estonian startup, is building a tool that automates road data cpature to improve maintenance and operations through computer-vision hardware and AI-driven SaaS.	Digital Twins

Table 4: Smart Work Zones

Link	Source	Date Published	Notes	Subtopic
https://workzonecameras.penndot.gov/about/	Pennsylvania DOT	NA	"Automated Work Zone Speed Enforcement (AWZSE) uses portable systems (either vehicle- or other apparatus-mounted) to detect and record vehicles exceeding work zone posted speed limits by 11 miles per hour (mph) or more using electronic speed timing devices (radar or nonradar). The Pennsylvania State Police is responsible for reviewing and affirming select violations. Violation notices that have been reviewed and affirmed by PSP will include a statement affirming the violation. PSP also provides field speed and quality control testing."	Speed Enforcement
https://workzonecameras.penndot.gov/wp-content/uploads/2023/04/2023PennDOT-AWZSE-Report_033023.pdf	Pennsylvania DOT	2023	Summary of success of Automated Work Zone Speed Enforcement (AWZSE) program. Including number of citations and data suggesting decreased work zone crash numbers.	Speed Enforcement
https://www.ny.gov/work-zone-safety-awareness/automated-work-zone-speed-enforcement-program	New York State	NA	Automated Work Zone Speed Enforcement Program. System automatically takes photo of vehicles speeding and issues citation.	Speed Enforcement
https://ops.fhwa.dot.gov/publications/fhwahop17044/fhwahop17044.pdf	FHWA	2017	Automated Speed Enforcement system, uses traffic cameras to capture speeding in work zones and issue violations. Data suggests decreased observed speeds in work zones after deploying.	Speed Enforcement
https://www.scirp.org/journal/paperinformation.aspx?paperid=100074	Peer Reviewed Journal	July 2020	This paper discusses work zone surfaces and pavement marking infrastructure that can support AVs. The paper makes recommendations on pavement markings that should be used to enable the movement of AVs through work zones.	Pavement Markings
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-20-06-30-02.pdf	Caltrans	June 2020	Results of a study evaluating automated solutions to "lane closure with reversible control" in work zones. "This research study evaluated methods of traffic control for mitigating wrong way movements from low volume access points in work zones that use reversible control. A literature review was conducted to identify traffic control systems that could address this problem. The most relevant devices found were a type of traffic control system known as a Driveway Assistance Device (DAD). A commercial DAD was selected for testing that was made by Superior Traffic Services (STS) of Missoula, Montana. A test plan along with a test protocol was developed and testing was conducted. Testing was conducted in two groups using a total of 11 volunteer test drivers. Of the 11 test drives, two drivers entered the intersection when a red signal was displayed by the DAD. Some driver anxiety was observed about unknown wait times, so it was recommended that the onboard Changeable Message Sign (CMS) be used to display wait times. Testing with the onboard CMS was not conducted due to impacts from the COVID-19 pandemic and other reasons. In addition to testing of existing equipment, new concepts were synthesized. These new concepts included using machine vision to ensure that all vehicles that entered the work zone exited before the traffic direction is reversed and adding micro radio transmitters to a Traffic Control System (TCS) in order to provide directions to motorists. A proposal was also generated for modifications that can be made to existing DADs that included adding a gate arm and adding an intrusion detection system."	Flagging Operations
https://ops.fhwa.dot.gov/publications/fhwahop19050/fhwahop19050.pdf	FHWA	June 2019	Installed devices on portable arrow board displays gather and communicate lane closure status data from stationary and rolling work zones of short duration maintenance activities. Lane closure status information is integrated into two of MnDOT's existing systems: the State's Advanced Trafc Management System (ATMS) and the Road Condition Reporting System (RCRS), both managed and operated by the Regional Trafc Management Center (RTMC). The outcome from this integration will result in the communication of real-time traveler information to the public, both through dynamic message signs (manually) and the State's 511 system (automatically). The system will also allow MnDOT to monitor and evaluate work zone performance measures using the available lane closure data. Starting in April 2018, MnDOT tested the integration of lane closure messages from 20 connected arrow boards and their ATMS and RCRS systems during a one-year testing period in the Minneapolis/St. Paul metropolitan area. This deployment is part of the ENTERPRISE Pooled Fund Study vision to procure State and local systems that follow common requirements and meet existing and future traveler information needs. Existing truck-mounted arrow boards used for short-duration work zones and maintenance activities will be equipped with an Arrow Board Reporting System.	Traveler Displays
https://www.wanco.com/product/hybrid-smart-work-zone-systems/	Wanco	NA	"Wanco Smart Work Zone Systems help keep roads safe by providing motorists with real-time traffic updates as they approach a work zone. Hybrid systems combine technology such as radar, Bluetooth, video cameras and computer systems for monitoring and communicating updates to drivers when there are hazardous or unexpected driving conditions. The technologies work together as one cohesive unit in order to provide the safest work zone possible. - Trucks Entering Highway Warning Systems identify when construction vehicles are leaving a worksite and entering the highway, to warn drivers of oncoming vehicles - Queue Detection & Warning Systems identify stopped or slowed traffic in real time, to warn drivers ahead of time and prevent accidents - Travel Time Measurement Systems use sensors to calculate accurate travel times, and dynamic messaging to communicate those times to drivers - Traffic Camera Systems provide remote monitoring of traffic and road conditions, so incidents can be quickly identified and cleared - 24/7 online access is available for monitoring and controlling the entire system from any location - Automatic alerts can send real-time updates to the contractors and DOT personnel via email or text - All systems can work together seamlessly"	Traveler Displays
https://www.wanco.com/wp-content/uploads/2020/06/brochure_WancoITS.pdf	Wanco	NA	Brochure on Wanco ITS for ITS data capture and management.	ITS in Work Zones

Link	Source	Date Published	Notes	Subtopic
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/training/courses_programs/rsa_program/RSP_Guidance_Documents_Download/RSP_EndOfQueueWarning_Guidance_Download.pdf	National Work Zone Safety Information Clearinghouse	Sept 2015	Fact sheet regarding TxDOT implementation of a portable work zone intelligent transportation queue detection and warning system upstream of merging taper for construction. Crashes reduced by up to 45%, saving up to $1.8 million in societal crash costs.	ITS in Work Zones
https://portal.ct.gov/-/media/DOT/documents/dhighwayoperations/ITS/April2017CTDOTSmartWorkZonesGuidepdf.pdf	Connecticut DOT	April 2017	"This guide provides an introduction to SWZ concepts, components, goals, and objectives to be pursued by CTDOT, as well as an overview of different SWZ applications to be used by CTDOT. These applications currently include, but are not limited to, real-time traveler information notifications, performance measurements, queue warning, intrusion detection, excessive speed warning, entering/exiting vehicle notifications, and over height vehicle notifications."	ITS in Work Zones
https://ftp.txdot.gov/pub/txdot-info/trf/smart-work-zone-guidelines.pdf	Texas DOT	Oct 2018	"This guide provides an introduction to six Smart Work Zone (SWZ) systems that have been identified by TxDOT for use in work zones. It includes System Selection Decision Tools, which use project specific criteria for Go/No-Go decisions for each of these systems and Function Selection Decision Tools to meet specific project needs. These tools are intended to streamline the design process and produce a uniform SWZ delivery across the State. The six SWZ systems include the following: - Temporary Queue Detection: To address the safety issue of slowed or stopped traffic on the approaches of work zones. - Temporary Speed Monitoring: To improve speed zone compliance and encourage more uniform speeds. - Temporary Construction Equipment Alerts: To inform motorists when material handling vehicles enter the traffic stream. - Temporary Travel Time Display: To help approaching motorists make informed decisions about route choices. - Temporary Incident Detection and Surveillance: To provide situational awareness and faster responses to incidents. - Temporary Over-Height Vehicle Warning: To provide advance warning alerts for projects with low structures. This technical report presents TxDOT's recommendations for the basic guidelines for incorporating Intelligent Transportation Systems (ITS) into the TCP for roadway construction projects. These guidelines are intended to clarify what ITS Systems are appropriate for "Smart Work Zones" on TxDOT projects, provide general design and deployment guidance for these systems, and support state-wide work zone ITS standards and specifications."	ITS in Work Zones
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/training/fhwa_wz_grant/artba_use_swz_technology-508.pdf	National Work Zone Safety Information Clearinghouse	2019	"One way to reduce crashes between slow-moving construction vehicles entering and exiting work spaces and high-speed traffic is to warn approaching drivers of the presence of the slowmoving vehicle. Most agencies specify the use of static warning signs indicating that trucks may enter the roadway from the work space. Unfortunately, because motorists often pass these signs repeatedly without encountering construction vehicles entering or exiting the work space, they eventually learn to disregard the sign and fail to remain vigilant to the possibility of a slow-moving vehicle in the vicinity. Smart work zone (SWZ) systems exist that can detect a construction vehicle as it approaches the access point to exit the work space and automatically activate a warning to motorists upstream. Radar, microwave, and video detection can all be used for this purpose, although radarbased detection is likely to be the lowest cost. Both static warning signs with activated flashing lights and portable changeable message signs (PCMSs) with messages that are activated when a truck is detected can be used. Certain work space access point configurations will allow the sensor to be mounted directly on the sign and aimed where the construction vehicles will approach the exit."	ITS in Work Zones
https://ver-mac.com/imports/medias/produits/series/web-jamlogic-2018-04-04.pdf	Ver-Mac	NA	Overview of product available through Ver-Mac, their Jamlogic, a smart work zone enterprise that collects data and disseminates it across connected equipment.	ITS in Work Zones
https://transportationops.org/case-studies/fdots-smart-work-zone-initiative	National Operations Center of Excellence	March 2021	Overview of Florida DOT smart work zone initiative, including: - Queue detection and warning systems - Speed monitoring and management systems - Construction equipment alert system - Travel time monitoring system - Over-height vehicle warning systems - Vehicle intrusion systems - Reduced speed alert systems	ITS in Work Zones
https://portal.ct.gov/DOT/CTDOT-Press-Releases/2023/CTDOT-Launches-Work-Zone-Speed-Safety-Camera-Pilot-Program	Connecticut DOT	March 2023	Connecticut DOT deployed the speed safety camera program, using radar and camera technology to capture license plates of drivers exceeding 15 mph over the speed limit in work zones.	Speed Enforcement
https://azdot.gov/sites/default/files/media/2020/09/ADOT-SWZ-Study-WP-1-Nationwide-Review-of-SWZ-Tech.pdf	Arizona DOT	Feb 2019	Overview of Arizona DOTs smart work zone applications program. Featuring queue warning system, variable speed limits, traffic data collection, travel time/delay, traffic monitoring, entering/exiting vehicle notification, and real time traver information.	ITS in Work Zones

Link	Source	Date Published	Notes	Subtopic
https://enterprise.prog.org/wp-content/uploads/ENT-Arrow-Boards-Ph3-Eval-FINAL-012120.pdf	ENTERPRISE Pooled Fund	Jan 2020	"The ENTERPRISE Pooled Fund Study has completed two previous efforts supporting transportation agencies integrating arrow board status information from the field into traveler information systems to alert TMC operators and travelers in real-time, for example, of a lane closure. Per direction from the ENTERPRISE Board, Phase 1 and Phase 2 were completed in 2017 in order to properly assess needs and potential solutions before deployment and evaluation of a real-time arrow board system at one or more ENTERPRISE agency sites. In 2018, the Minnesota Department of Transportation (MnDOT) conducted a one year pilot project through a contract with a vendor (Street Smart) that installed a monitoring device on 20 arrow boards that provided arrow board status information (e.g. right arrow on, left arrow on) to the vendor's server. The arrow board status information from the server was then integrated with MnDOT's Advanced Traffic Management System (ATMS) and then their Road Condition Reporting System (RCRS). In 2019, the Iowa DOT had access to 5 equipped arrow boards with reporting capabilities (Street Smart, iCone, Ver-Mac) to provide real-time arrow board status information to the vendor's server. This project evaluated the deployments of the arrow board concept in these two ENTERPRISE member states (Minnesota and Iowa). In addition, an overview of the Regional Transportation Commission (RTC) of Southern Nevada real-time arrow board reporting system deployment is included as another perspective. Overall the data analysis for MnDOT and the information gathered from interviews from MnDOT and Iowa DOT indicate a benefit to the traveling public and Transportation Management Center (TMC) operators with additional information on the overall network with the location of lane closures provided by arrow board reporting systems."	Pooled Fund on ITS
https://www.autoflagger.com/	Safety Technologies Auto Flagger	NA	Available product from manufacturer. Portable automated flagger assistance device, removes human flagger from roadway.	Flagging Operations
https://dot.ca.gov/programs/construction/safety-traffic/flagging-handbook	Caltrans	July 2020	"The AFAD is an automated flagging device operated by a flagger located off the roadway and away from traffic. The device is essentially an extension of the flagger's arm. Flaggers use a remote control instead of a SLOW/STOP paddle to control the movements of traffic. The device is considered a safety enhancement for projects that use reversible temporary traffic control because it minimizes flaggers' direct exposure to traffic by allowing them to control traffic from an area away from the traveled way. - Operator must be a certified flagger and must be certified by the manufacturer to operate the specific automated flagger assistance device. - Remotely operated by one operator at a central location or by separate operators near each device location. When using a single operator, the AFADs must be located so the operator can see both devices. - AFADs must be located such that approaching road users will have sufficient distance to be able to stop at the intended stopping point. - AFAD trailers are to be placed on the roadway shoulder. There must be a minimum shoulder width of 4 feet and approximately 3 feet of adjacent level area available next to the shoulder to place a trailer mounted AFAD. - Placement of the AFAD must not impair access for pedestrians and bicycles, if that is the case, make provisions for alternate access. - The AFAD gate arm must not extend into the opposite lane. - 4 to 6 cones may be placed on the lane line approaching the flagging station to address vehicles crossing over to go around the AFAD."	Flagging Operations
https://spexternal.modot.mo.gov/sites/cm/CORDT/cmr17-010.pdf	Missouri DOT	Aug 2017	"Flagger safety is an important issue in work zones due to the proximity of the flagger to traffic. Some strategies for improving flagger safety include slowing down approaching vehicles or removing flaggers from the immediate vicinity of traffic. The Automated Flagger Assistance Device (AFAD) is a system that can potentially accomplish both of the aforementioned strategies. In order to validate the effectiveness of AFADs in highway work zones, field testing was performed using an AFAD with a Changeable Message Sign (CMS) on a 2-lane work zone in Missouri. The field study found that AFADs helped to lower approach speeds and encouraged vehicles to stop farther behind the AFAD than a traditional flagger. In addition, a driver intercept survey found that the AFAD was viewed favorably by the general public. These field results found that AFADs are more effective than human flaggers, and drivers prefer AFADs over human flaggers."	Flagging Operations
https://arrowes.com.au/product/estop-portable-traffic-signal-system/	Arrowes	NA	Equipment manufacturer. From Australia. eSTOP Portable Traffic Signal System. Remove work zone traffic controler and replace with mobile, battery operated traffic light. Can be controlled manually or automatic.	Flagging Operations
https://intrans.iastate.edu/app/uploads/2022/01/autonomous_connected_vehicles_in_WZs_investigation_w_cvr.pdf	Iowa DOT	Dec 2021	"It is anticipated that autonomous truck platooning could lead to many benefits, such as maximizing existing road capacity, decreasing fuel consumption through drafting, and reducing emissions. Despite the voluminous research on truck platooning, very little has been relevant to provide guidance to departments of transportation for operation in work zones. This study is the first research project that examined truck platooning in work zones. A networked or federated simulator was used in which a vehicle driven by a human subject encountered a truck platoon with the lead truck driven by a human driver. The experiment involved 10 scenarios composed of differences in education, truck signage, and number of trucks in the platoon. The results point to the importance of education as the post-education vehicle speeds increased between 8.6% and 12.9% across scenarios, and the distance headways decreased between 28.8% and 30%. The vehicles increased in efficiency while still staying under the work zone speed limit. On the other hand, the use of truck signage changed driver behavior in an arguably undesirable way by increasing the percentage of platoon bypasses. As the post-simulator survey revealed, 94% of the subjects believed it was safer not to bypass the truck platoon and yet about 34% chose to do so. This initial investigation into truck platooning near work zones is a beginning upon which further investigations on education, signage, and platoon size policies can continue."	Truck Platoons in Work Zones
https://www.nhtsa.gov/book/countermeasures/countermeasures/21-automated-enforcement	NHTSA	NA	Overview of use, effectiveness, legislation, and legality of automated enforcement as a countermeasure to reduce speeding and aggressive driving.	Speed Enforcement

Link	Source	Date Published	Notes	Subtopic
https://ahmct.ucdavis.edu/mtls	UC Davis	Oct 2012	Mobile Terrestrial Laser Scanning. "Surveyors are exposed to high-speed traffic, often with no positive barrier or protection, putting them at high risk when surveying the highway. MTLS provides a tool for surveyors to do their job in an innovative way while working safely from a vehicle moving at highway speed. In addition to the clear safety improvement provided, MTLS provides multiple efficiency improvements. First the collection occurs at highway speed so that many miles of roadway can be collected in a single day. Second, the system collects location, image, and intensity for a huge number of points every second, generating a so-called point cloud. Using this point cloud, surveyors, engineers, and others can extract information, for example dimensions, while in the office, removing the need to return to the field for measurements. Availability of the point cloud enables innovative applications including visualization and virtual design and construction."	Land Surveying

Table 5: Connected and Autonomous Vehicles (CAVs)

Link	Source	Date Published	Notes	Subtopic
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-23-06-30-01.pdf	Caltrans	April 2023	Report evaluating the Bosch mobile app for Wrong-Way Driver (WWD) detection, an infrastructure free algorithm to detect WWD using a GPS and in-vehicle system or smartphone app to alert drivers.	Wrong Way Driving Detection
https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/SWZ/TX-CWZ-peer-exchange_Texas_DOT.pdf	National Work Zone Safety Information Clearinghouse	Nov 2022	Slidedeck on Texas connected freight corridors. Proposed applications include: advancd traverl information system, eco-dynamic routing, work zone warnings, pedestrian/animal warnings, truck parking availability/reservation, border wait times, truck signal priority, low bridge height warnings, traffic & road info for truck platooning, EEBL alerts from trucks ahead, traffic queue warnings, road weather warnings, and wrong way driving alerts.	Freight Applications
https://cvp.nyc/	New York City DOT	NA	"NYC is one of three Connected Vehicle (CV) pilot deployment sites selected by USDOT to demonstrate the benefits of this new Connected Vehicle technology. The other sites are in Wyoming, which focuses on interstate routes and commercial vehicles, and Tampa, which will be testing a number of applications in a mid-sized urban environment on a relatively small number of vehicles. The NYC deployment is primarily focused on safety applications – which rely on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-pedestrian (IVP) communications. These applications provide drivers with alerts so that the driver can take action to avoid a crash or reduce the severity of injuries or damage to vehicles and infrastructure."	Smart City Testbed
https://www.vtti.vt.edu/vcc/index.html	Virginia Tech Transportation Institute	NA	"To facilitate the understanding of CV deployment, the Virginia Department of Transportation (VDOT) has partnered with the Virginia Tech Transportation Institute (VTTI) to create the Virginia Connected Corridors (VCC). The VCC is a CV environment that enables the development and assessment of early stage connected and automated vehicle (CAV) applications. The VCC comprises more than 60 roadside units (RSUs) which are connected to a low-latency backhaul network via dedicated short-range communications (DSRC) and cellular technology. The VCC strives to provide an open application development environment where third party developers may bring their applications and tap into existing infrastructure resources and systems to minimize time to demonstration and deployment. Developers may create applications that run directly on the VCC Cloud computing environment or access VCC data through a Public API depending on which is most appropriate."	Smart City Testbed
https://www.its.dot.gov/pilots/pilots_thea.htm	USDOT	NA	Overview of the Tampa (THEA) connected vehicle pilot deployment program.	Smart City Testbed
https://www.its.dot.gov/pilots/pilots_nycdot.htm	USDOT	NA	Overview of the New York City (NYC) DOT connected vehicle pilot deployment program.	Smart City Testbed
https://www.its.dot.gov/pilots/pilots_wydot.htm	USDOT	NA	Overview of the Wymoing (WY) DOT connected vehicle pilot deployment program.	Smart City Testbed
https://informedinfrastructure.com/75284/colorado-department-of-transportation-selects-yunex-traffic-to-expand-statewide-connected-vehicle-program/	Media	July 2022	"Yunex Traffic, a global leader in intelligent traffic systems, today announced that the Colorado Department of Transportation (CDOT) has selected the company as one of two selected vendors to provide equipment and expertise to expand the state's connected vehicle technology. During the initial one year contract, Yunex will assist the department in deploying, configuring and maintaining 150 of the company's new signature RSU2X roadside units as part of the CDOT Connected Vehicle (CV) Program's strategic expansion. CDOT's federal project represents one of the largest single deployment of RSU2X roadside units to date."	Technology
https://gis.penndot.gov/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Operations/Pennsylvania_Automated_Vehicle_Strategic_Plan.pdf	Pennsylvania DOT	July 2018	Overview of Pennsylvania's connected and automated vehicle strategic plan. Includes planning and considerations for leveraging data collected from CAVs to improve maintenance and operation tasks. Such as: "- Leveraging CAV data for roadway maintenance can replace the need for extensive data collection efforts, but it will require installation of appropriate connected infrastructure assets. CAV may supplement data needs for roadway conditions such as pothole locations, insufficient pavement markings, and inclement. This will require large collaboration efforts with the private sector operators and manufacturers of CAV. - Proper data management will be a critical foundational need addressed for the success of CAV. Leveraging CAV data for maintenance and operations can replace the need for data agreements with private traffic data providers, diminish the need for vehicle detection systems, assist with incident response, and allow for performance metrics and predictive algorithms to better manage traffic, among others."	Framework

Table 6: Traffic Incident Response

Link	Source	Date Published	Notes	Subtopic
https://ahmct.ucdavis.edu/responder	UC Davis	NA	"Caltrans maintenance staff is a first responder to incidents on the state roadways. They must collect information, determine the appropriate response, and access and manage resources at-scene. Caltrans currently does not have an efficient means to collect at-scene incident information and share this information with their transportation management center (TMC) and other emergency responders. In most districts, emergency responders rely on voice communications to exchange information. However, Caltrans rural districts lack the ability to distribute incident support information to responders via data networks. Such information could better prepare responders for incident support, provide assistance for incident management, and guide responders in making safe and sound decisions. These rural districts have areas with no communication availability including no two-way radio communication and/or cellular coverage. Caltrans needs a communication tool for first responders to allow photos, drawings, weather information, and maps to be shared between responders and a TMC during an incident via cellular, satellite, or other forms of communications, that will work anywhere in the State."	Rural Applications
https://enterprise.prog.org/wp-content/uploads/ENT-Automated-Incident-Detection-FR-Jan-2022.pdf	ENTERPRISE Pooled Fund	Jan 2022	"Traffic Management Center (TMC) operators need to be alerted of roadway incidents (e.g., crashes, stalled vehicles, slowed or stopped traffic) in a timely manner to initiate response efforts and manage the resulting traffic implications. Commercially available products can provide automated incident detection (AID) functionality with alerts to TMC operators. This project researched the state of practice for commercially available AID systems. The project focused on products and tools that detect multiple types of common roadway incidents (e.g., crashes, stalled vehicles, debris, slow or stopped traffic) and provide alerts to TMC operators. The project objectives were to understand the various AID capabilities offered and to define common user needs for TMC operator use of AID systems. To accomplish the objectives, the project identified 42 common TMC operator user needs for AID that were used to guide seven vendor demonstrations of AID products to document their capabilities. Two transportation agencies also demonstrated platforms developed in-house to assist in AID. Finally, a peer exchange webinar featured seven transportation agencies highlighting their experiences with AID products. The AID systems reviewed for this project vary in detection capabilities, detection coverage, and detection environments. In addition, all products or agency platforms are configurable, provide alerts to TMC operators and can be integrated with an agency's ATMS. The product capabilities documented and the TMC operator common user needs for AID can be used and modified by ENTERPRISE members to identify their agency's specific needs for deploying AID systems."	Communication

Table 7: Intelligent Transportation Systems (ITS)

Link	Source	Date Published	Notes	Subtopic
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-19-09-30-03.pdf	Caltrans	June 2020	"This report presents results for research on a Vision-Based Site Monitoring (VBSM) system for monitoring Wrong-Way Driving (WWD) events. This system integrates a camera, solar power panels, and a modem into a pole-mounted package for deployment on freeway exit ramps to monitor for WWD events. The system incorporates on-camera analytics for WWD detection as well as traffic counts. Collection of WWD video is triggered by the camera analytics, and the system stores the videos for a period before and after the WWD event. The system was deployed at ten exit ramps in Northern California, and two exit ramps in Southern California. Data collected over a 39-month period (June 5, 2016-August 31, 2019) is presented, illustrating the effective performance of the VBSM system as a self-contained system for WWD monitoring application. The analysis of the data for WWD events collected shows agreement with the results of prior research studies, while providing a more complete picture of driver behavior."	Wrong Way Driving Detection
https://enterprise.prog.org/projects/potential-approaches-for-wrong-way-driving-applications/	ENTERPRISE Pooled Fund	2021	"Wrong-way driving is a growing concern on roadways, especially because resulting crashes tend to be severe and often result in fatalities and serious injuries. Transportation agencies are deploying on-road countermeasures at select locations. However, these countermeasures can only go so far to reduce wrong-way crashes. In-vehicle navigation systems and mobile applications hold significant potential to reduce wrong-way crashes. These interventions could reach many more drivers than on-road countermeasures alone, by providing alerts at all times and all locations while the application is being used. During this project, the ENTERPRISE Pooled Fund conducted outreach to automobile manufacturers and mobile app developers to explore the potential for in-vehicle navigation systems and mobile apps to provide wrong-way driving alerts."	Wrong Way Driving Detection
https://trafficalm.com/wwa/	Trafficalm	NA	Available product for wrong way warning systems. Can be retrofitted with existing infrastructure, adds radar technology to detect wrong way vehicles and deliver message.	Wrong Way Driving Detection
https://ops.fhwa.dot.gov/publications/fhwahop20003/fhwahop20003.pdf	FHWA	June 2020	"Automated traffic signal performance measures (ATSPM) are recent tools available to agencies that manage traffic signal systems. They have been shown to greatly enhance agencies' situational awareness regarding operation and maintenance of their signals that was previously only available through field operations or time-consuming analysis. ATSPMs have helped agencies quickly identify and proactively respond to operational and maintenance issues, improve traffic signal timing, and easily communicate outcomes internally and to decision makers and the public. ATSPMs can also improve the capabilities of agencies and help move away from reactive management that responds to problems as they are reported, and toward proactive management that takes action based on direct measurement of performance. This report proposes a methodology for estimating benefits and costs. In addition, the report includes detailed information from six case studies of early adopters of ATSPMs, and summarizes key factors of successful implementations. As part of this research, six early adopter agencies were interviewed. This included three State agencies: Utah Department of Transportation (UDOT), Georgia Department of Transportation (GDOT), and Pennsylvania Department of Transportation (PennDOT); and three local agencies: Lake County Department of Transportation (LCDOT); Clark County (WA); and Maricopa County Department of Transportation (MCDOT)."	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop20002/fhwahop20002.pdf	FHWA	March 2020	"Automated traffic signal performance measures (ATSPM) will revolutionize the management of traffic signals by providing the high-resolution data needed to actively manage performance." "Automated traffic signal performance measures (ATSPM) are an enabling technology that leverages data collection and analysis for proactive traffic signal system management. This report highlights the technical outreach undertaken by FHWA to assist States in meeting their Every Day Counts (EDC) Round 4 implementation objectives with respect to ATSPM. The outreach activities described in this report include use cases, workshops, webinars, and case studies." "Automated traffic signal performance measures are a collection of data analytics tools and approaches that automatically collect and convert high-resolution traffic controller data into actionable performance measures." "There are more than 330,000 traffic signals operating in the United States, and highway agencies typically retime these signals on a threeto five-year cycle at a cost of approximately $4,500 per intersection. For many of these signals, citizen complaints are the primary measure of performance. Since performance data is not continuously collected at most intersections, intersection performance is simulated using software models based on periodic and manual traffic data collection, which adds cost and time to the signal retiming process."	ITS at Intersection
https://ops.fhwa.dot.gov/arterial_mgmt/pdfs/EDC-4-Factsheet_ATSPMs.pdf	FHWA	NA	Fact Sheet on Automated Traffic Signal Performance Measures (ATSPMs). "ATSPMs modernize traffic signal management by providing high-resolution data to actively manage performance and improve safety and customer service while cutting congestion and costs." "The technology is cost effective, as ATSPMs can be applied to a wide range of signalized intersections and use existing infrastructure to the greatest extent possible. ATSPMs will also support the validation of other technologies and operational strategies, such as adaptive signal control and emerging connected vehicle applications." Benefits of ATSPMs include targeted maintenance, improved operations, and increased safety.	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18048/fhwahop18048.pdf	FHWA	Sept 2018	Summary of a case study for Utah DOT impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18050/fhwahop18050.pdf	FHWA	Sept 2018	Summary of a case study for Georgia DOT impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18054/fhwahop18054.pdf	FHWA	Sept 2018	Summary of a case study for Pennsylvania DOT impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection

Link	Source	Date Published	Notes	Subtopic
https://ops.fhwa.dot.gov/publications/fhwahop18052/fhwahop18052.pdf	FHWA	Dec 2018	Summary of a case study for Arizona Maricopa County impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18049/fhwahop18049.pdf	FHWA	Dec 2018	Summary of a case study for Washington state Clark County impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18056/fhwahop18056.pdf	FHWA	Jan 2019	Summary of a case study for Florida Seminole County impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://ops.fhwa.dot.gov/publications/fhwahop18055/fhwahop18055.pdf	FHWA	Jan 2019	Summary of a case study for Portland Bureau of Transportation impelementing Automated Traffic Signal Performance Measures (ATSPMs).	ITS at Intersection
https://udottraffic.utah.gov/atspm/	Utah DOT	NA	Public facing tool for signals in Utah equipped with ATSPM	ITS at Intersection
https://traffic.dot.ga.gov/ATSPM/	Georgia DOT	NA	Public facing tool for signals in Georgia equipped with ATSPM	ITS at Intersection
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-23-04-05-01_0.pdf	Caltrans	April 2023	"Caltrans is looking to improve crosswalk technology in urban areas. Specifically using a crosswalk sensor which can detect pedestrian motion and extend walk time accordingly. Caltrans is interested in three sensors: AGD 326, MS Sedco SmartWalk XM, and iComs TMA-011 LV. The objective of this research is to evaluate each of the three sensors and help Caltrans make decisions in choosing a sensor that satisfies Caltrans' purposes. The systems were evaluated using an apparatus mounted on a truck bed, a phone-controlled camera, a spray-painted grid on the AHMCT test track, a custom LED indicator cable, and a portable charger. This is the final report for the overall task, TMS Innovative Product Proof of Concept (POC) Support, as well as the detailed report for Technical Evaluation of Detectors for Pedestrian Walk Time Extension. Overall, AHMCT would recommend the AGD 326 sensor to be the best candidate for Caltrans' purposes. The AGD 326 has the most user-friendly interface, which makes the setting adjustment process straightforward. The AGD 326 sensor is the only candidate that allows flexibility in adjusting the detection zone parameters to match the desired crosswalk parameters. The AGD 326 also presents a visual demonstration in its manual where the user can check the integrity of the sensor detection parameters. These unique features are more valuable when compared to the SmartWalk XM and iComs features."	ITS at Intersection
https://enterprise.prog.org/wp-content/uploads/ENT-Ped-Detection-Improved-Safety-FR-Jan-2022.pdf	ENTERPRISE Pooled Fund	Jan 2022	Review of detection-based technologies with real-time alerts for pedestrian safety at intersections/crossings. Key technologies included: - !important: Smartphone app that alerts pedestrians, alerts drivers, and triggers brakes on connected vehicles automatically - TravelSafely: Smartphone app that connects userswith smartcity infrastructure - Applied Information and TravelSafely: Pedestrian corssing safety system with roadside signs, audible alerts, and connection to smartphone app - Applied Information and Qualcomm and TravelSafely: System linking traffic signals and connected roadway users and devices - Derq/ FLIR: Software application using AI to run real-time edge analytics, enable V2X applications, and provide safety and traffic insights - MH Corbin/ Bosch: Utilizes video images from cameras to detect and communicate the presence of a pedestrian - Draper (PathScout system): Vehicle sensor using mobile phoneGPS data and LiDAR to "see" pedestrians - Reflective Surface for Intelligent Transportation Systems (REITS): Wearable device to allow autonomous vehicles to detect pedestrians - Sensol: High-tech illuminated crosswalk - TAPCO/ FLIR: Thermal detection-activated Rectangular Rapid-Flashing Beacon (RRFB) Pedestrian Crosswalk System - Viziblezone: A vehicle integrateed 'pedestrian detector' that pairs with a car infotainment system or smartphone - MultiNet: Uber's self driving AI system that detects and predicts the motions of obstacles from autonomous vehicle lidar data - VectorNet: Waymo's AI solution that uses vectors to predict pedestrian, cyclist, and driver behavior	ITS at Intersection
https://www.dot.state.mn.us/its/projects/2016-2020/systemsengineeringforitsandcav/floodwarningse.pdf	Minnesota DOT	May 2019	Minnesota DOT application of ITS infrastructure and CAV technology to automatically detect and warn drivers of road flooding.	ITS for Flood Warning
https://www.wdrb.com/news/louisville-leaders-installing-flood-warning-systems-in-underpasses-prone-to-flooding/article_f6a566fe-d3c7-11ed-8a7c-f35650da6c7f.html	Media	April 2023	"Now, city leaders are moving forward with a high-tech solution from Louisville Metro's Department of Civic Innovation and Technology. The department recently received $2 million from the U.S. Department of Transportation as part of a new program called Strengthening Mobility and Revolutionizing Transportation (SMART). We are excited and grateful for this award to implement our ViaSmart proposal," Louisville Mayor Craig Greenberg said. "This funding will be used to install smart technology at four of our most dangerous, flood-prone underpasses. This will allow us to better manage traffic flows, enhance public safety, and support our Vision Zero goals. Thank you to the Department of Transportation and the SMART program for this important investment." The system contains high-tech sensors and other technologies to alert drivers when a viaduct is flooded — or if a vehicle is too tall to enter. Features include intelligent traffic lights, which won't allow vehicles or pedestrians enter flooded underpasses when sensors detect high water. Intelligent message boards will also alert people when the vehicle's height won't clear the top of the viaduct. Smart street lights will be equipped with bright bulbs that will turn red when an underpass is flooded. Free wi-fi for residents is built into the equipment. "	ITS for Flood Warning

Link	Source	Date Published	Notes	Subtopic
https://www.mdpi.com/1424-8220/21/14/4942	Peer Reviewed Journal	July 2021	"Scour around bridge piers remains the leading cause of bridge failure induced in flood. Floods and torrential rains erode riverbeds and damage cross-river structures, causing bridge collapse and a severe threat to property and life. Reductions in bridge-safety capacity need to be monitored during flood periods to protect the traveling public. In the present study, a scour monitoring system designed with vibration-based arrayed sensors consisting of a combination of Internet of Things (IoT) and artificial intelligence (AI) is developed and implemented to obtain real-time scour depth measurements. These vibration-based micro-electro-mechanical systems (MEMS) sensors are packaged in a waterproof stainless steel ball within a rebar cage to resist a harsh environment in floods. The floodwater-level changes around the bridge pier are performed using real-time CCTV images by the Mask R-CNN deep learning model. The scour-depth evolution is simulated using the hydrodynamic model with the selected local scour formulas and the sediment transport equation. The laboratory and field measurement results demonstrated the success of the early warning system for monitoring the real-time bridge scour-depth evolution."	ITS for Flood Warning

Table 8: Transit and Shuttles

Link	Source	Date Published	Notes	Subtopic
https://www.rtd-denver.com/news-stop/news/denver-launches-first-autonomous-shuttle	Regional Transportation District	Jan 2019	Press release about Denver Regional Transportation District's electric and autonomous shuttle pilot program - EasyMile.	Autonomous Shuttle
https://www.rtd-denver.com/sites/default/files/files/2019-09/61AV-project-recap-aug2019.pdf	Regional Transportation District	Aug 2019	Final report on Denver Regional Transportation District's autonomous shuttle pilot program. Includes objectives, costs, and lessons learned.	Autonomous Shuttle
https://www.us-ignite.org/blogs/adapting-transport-for-autonomous-food-delivery/	Media	NA	Press release about EasyMile in Colorado using fully autonomous shuttle for delivery trips from a local storage facility to a local food bank.	Autonomous Shuttle
https://enterprise.prog.org/wp-content/uploads/ENT-Infra-Impacts-AV-Demos-FR-Jan-2022.pdf	ENTERPRISE Pooled Fund	Jan 2022	"Automated vehicle (AV) demonstrations are becoming more widespread, however the infrastructure changes and needs required for AVs may not be clear to transportation agencies. To help ENTERPRISE agencies prepare for future AV demonstrations and operations, this project captured insight from agencies that have conducted low-speed AV shuttle demonstrations and identified the likely impacts of AVs on infrastructure operations. Specifically, this effort focused on low-speed AV shuttles with the intent to understand whether infrastructure changes and the roles of agency and private-sector stakeholders are representative of needs and roles in future, long-term AV deployments. Information was collected through a literature review and interviews with 12 AV deploying agencies in the United States and Canada. It was found that identified impacts to agency infrastructure and staff vary greatly depending on the use case and AV shuttle provider. The types of infrastructure changes for AV shuttle deployments include pavement markings, signage, roadside units, traffic signal timing adjustments, charging stations, secured parking areas, vegetation management, and modifications to construction schedules. The results of this project include discussion on the nature of these impacts, as well as a discussion on the reasons these impacts may be greater for some agencies than others."	Autonomous Shuttle
https://www.transit.dot.gov/funding/grants/grant-programs/fiscal-year-2022-advanced-driver-assistance-systems-adas-transit	Federal Transit Administration	June 2023	FY22 FTA funded grants for Advanced Driver Assistance Systems (ADAS) for Transit Buses	ADAS for Buses
https://www.transit.dot.gov/sites/fta.dot.gov/files/2023-07/FTA-Report-No-0242-rev.pdf	Federal Transit Administration	Feb 2023	Summary of findings and lessons learned for the 11 Mobility on Demand Sandbox Demonstrations across the US. "The Federal Transit Administration (FTA) Mobility on Demand (MOD) effort was developed around a vision of a multimodal, integrated, automated, accessible, and connected transportation system in which personalized mobility is a key feature. In 2016, FTA selected 11 MOD Sandbox demonstration projects to test strategies that advance the MOD vision. In partnership with public transportation agencies, the MOD Sandbox Program explored the potential for innovations to support and enhance public transportation services by allowing agencies to explore partnerships, develop new business models, integrate public transit and MOD strategies, and investigate new, enabling technical capabilities through demonstration projects."	Automation for Buses
https://www.transit.dot.gov/sites/fta.dot.gov/files/2023-06/Transit-Bus-Automation-Quarterly-Update-Q1-2023.pdf	Federal Transit Administration	June 2023	Overview of USDOT funded projects across the US related to transit bus automation.	Automation for Buses
https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/118161/transit-bus-automation-project-transferability-automation-technologies-final-report-fta-report-no.pdf	Federal Transit Administration	Sept 2018	"This report examines the feasibility of transferring 13 current automated systems technologies from light-duty vehicles and commercial trucks to 40-ft diesel transit buses. It explores the associated technical and safety challenges of implementing those systems in transit buses and ways to overcome some of the identified barriers to implementation. The transferability of each systems was given a grade of Red, Yellow, or Green, with Green indicating most ready to be transferred. Transferring existing automation systems from other vehicle formats will generally require modification, replacement, or redesign of components and systems on the bus. Sensors are relatively mature and should be able to be adapted to buses without modification. To enable other automation systems, however, the transit bus industry will need to implement foundational and interfacing systems that can support electronic actuation. Modifications to propulsion systems should be more easily made than modifications to other foundational systems (i.e., steering and braking). Steering systems may require more modification, but heavy-duty vehicle steering solutions that enable automation exist and may not require extensive changes. Implementation of electronic control of a transit bus brake system appears to be a major challenge, as pneumatic brakes found in buses are less conducive to automation and more extensive design changes may be needed. Automated applications may require a new communication system architecture with bandwidth to carry numerous complex signals reliably. Finally, buses will require new human-machine interfaces to control automation systems, although these should be relatively easy to design and implement."	Automation for Buses
https://www.bbc.com/news/uk-scotland-edinburgh-east-fife-65589913	Media	May 2023	Driverless bus in Scotland. Drives pre-selected roads on a 14-mile route at speeds up to 50 mph.	Autonomous Bus

Table 9: Unmanned Aerial Vehicles (UAVs)

Link	Source	Date Published	Notes	Subtopic
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/UCD-ARR-22-11-30-01.pdf	Caltrans	Nov 2022	"This research investigated the possibility of extending the range of existing wireless communications infrastructure for a variety of remote communication use cases in existing rural projects, as well as existing California Department of Transportation (Caltrans) rural operations. The goal was to evaluate the benefits and drawbacks of the aerial repeater concept via investigative flights. The primary goal of this research project was to develop a prototype unmanned aerial system (UAS) containing a communications payload providing aerial network data transfer between a cellular data network backhaul and ground-based Wi-Fi (IEEE 802.11x Wireless LAN) clients. The UAS would allow for deployment within the State highway system right of way, thus extending ubiquitous low-cost network data services further into remote rural areas."	Rural Communication
https://www.dartdrones.com/drones-for-state-department-of-transportations/	Media	Jan 2022	"So how do state DOTs use drones? DOTs in America (and world-wide) are using drones for an array of applications, including bridge inspections, accident assessments, surveying of roadways and other public infrastructure, risk identification, and many others depending on their state's needs. DOTs have many jobs, and each year they and their contractors are figuring out how to utilize drones in their projects. Drones are essentially flying sensors that can generate high resolution images, videos, thermal datasets, survey grade maps and 3D models (and more), and as such, they are highly sought out in the civil engineering sector. It's no wonder that a recent survey shows that forty-nine out of fifty states in the US are using drones." Tasks include: Tracking and monitoring (construction projects, traffic patterns, accident clearing, raod congestion, surface deformatino/erosion, flooding, landslides, rockslides), inspections (routine maintenance, bridge supports, bridge deck, confined spaces, light poles, road damage, equipment condition, leaks and cracks), and data gathering (land surveying, asset inventory, asset management, operational research, scientific research, emergency response plans, LiDAR point clouds).	UAS Operations
https://www.government-fleet.com/332236/70-of-state-dots-use-drones-heres-how-they-use-them	Media	May 2019	"The use of drones, also known as unmanned aerial systems (UAS), among state Departments of Transportation has grown significantly, from 45% of state DOTs in 2018 to 72% in 2019, according to a May 2019 survey by the American Association of State Highway and Transportation Officials (AASHTO). The types of missions and research being conducted by state DOTs varies widely. AASHTO's survey finds that the top five drone missions in order of frequency are: 1) photo and video gathering mainly of infrastructure projects; 2) surveying; 3) inspecting infrastructure including bridges, signage, light poles, and pavement; 4) responding to emergencies and natural disasters; and 5) for public education and outreach. In total, state DOTs identified more than 20 mission types including the observation and management of endangered species, underwater vegetation, and traffic monitoring. The survey also found that 29 states said drones are helping them save money. How much? The Michigan DOT calculates that a manual inspection of the deck on a four-lane divided highway bridge located near a metropolitan area would take a two-person crew using heavy equipment eight hours to complete — at a cost of $4,600. But the agency said conducting the same inspection using drones would take one pilot and one spotter one hour to complete at a cost of $1,200 — a 74% savings. In addition, Michigan DOT estimates there would be an additional $14,600 in user delay costs from lane closures. No lane closures are necessary using drones. In addition to infrastructure inspections and crop health monitoring, the North Dakota DOT is deploying drones for emergency response as part of its IPP. In North Carolina, agency officials are gathering real-time data on the viability of commercial package delivery. Working with its private sector partners, the North Carolina DOT began in March executing hundreds of successful drone package deliveries using predetermined docking stations within a defined airspace. Conventional highways have for 60 years been the backbone of economic development in America," said Basil Yap, manager of the North Carolina DOT's UAS program. "Now, state DOTs are helping to plan and build highways in the sky. We know that commercial drone delivery is coming and our research is focused on helping small businesses develop this capability. AASHTO's May 2019 survey found that 36 state DOTs out of 50 have staff dedicated to drones: Alabama, Alaska, Arizona, Arkansas, California, Colorado, Delaware, Georgia, Idaho, Illinois, Iowa, Kansas, Kentucky, Louisiana, Maine, Massachusetts, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, Tennessee, Utah, Vermont, Virginia, Washington State, West Virginia, Wisconsin."	UAS Operations
https://arxiv.org/pdf/2205.04164.pdf	Peer Reviewed Journal Preprint	May 2022	"The EU-funded HERON project will develop an integrated automated system to adequately maintain road infrastructure. In turn, this will reduce accidents, lower maintenance costs, and increase road network capacity and efficiency. To coordinate maintenance works, the project will design an autonomous ground robotic vehicle that will be supported by autonomous drones. Sensors and scanners for 3D mapping will be used in addition to artificial intelligence toolkits to help coordinate road maintenance and upgrade workflows." Identified use cases of the HERON include: traffic cones placement/retreival, pothole maintenance, crack maintenance, road markings maintenance, and removable urban pavement maintenance. Vehicle requires 1 supervisor of the unmanned ground vehicle assisted by 1 drone pilot (as needed) to replace 2-3 workers needed for conventional tasks.	Ground Operations

Link	Source	Date Published	Notes	Subtopic
https://ops.fhwa.dot.gov/publications/fhwahop20063/fhwahop20063.pdf	FHWA	Feb 2022	"The Federal Highway Administration's (FHWA) Office of Operations has actively engaged in the national deployment of Traffic Incident Management (TIM) programs since the office was deployed. Public agencies are increasingly using Unmanned Aircraft Systems (UAS) for a variety of purposes and are developing sections to coordinate UAS use. Several Law Enforcement agencies have been using UAS for crash investigation and re-construction that is showing significant potential. The Primer describes how unmanned aircraft systems (UAS) can benefit traffic crash investigations and other traffic incident management-related activities. Presentation of legal considerations, operation, crash investigation applications, and implementation guidance are included, as well as the benefits of UAS with examples from States."	UAS Operations

Table 10: Framework and Legislation

Link	Source	Date Published	Notes	Subtopic
https://www.transportation.gov/sites/dot.gov/files/2021-01/USDOT_AVCP.pdf	US DOT	Jan 2021	USDOT's Automated Vehicles Comprehensive Plan. A good framework for deploying and operating AVs.	Framework
https://www.transportation.gov/sites/dot.gov/files/2021-01/USDOT%20Automation%20Activities_Appendix.pdf	USDOT	Dec 2020	USDOT's Overview of Automation Activities at US DOT. Describes a variety of considerations, in reasonable brevity, for deploying, researching, and related legislation for AVs.	Framework
https://leg.colorado.gov/sites/default/files/documents/2017A/bills/2017a_213_enr.pdf	Colorado	2017	Colorado state legislation related to autonomous vehicles.	Legislation
https://www.maine.gov/mdot/autonomous-vehicles/docs/2020/Autonomous%20Vehichle%20Rule%20Final%20Draft%2012.17.19.pdf	Maine	2019	Maine state legislation related to autonomous vehicles.	Legislation
https://www.azleg.gov/legtext/55leg/2R/laws/0256.pdf	Arizona	2022	Arizona state legislation related to autonomous vehicles.	Legislation
https://apps.azdot.gov/files/sitefinity-files/Executive-Order-2018-04.pdf	Arizona	2018	Arizona executive order related to autonomous vehicles.	Legislation
https://legiscan.com/OR/text/HB4063/2018	Oregon	2018	Oregon state legislation related to autonomous vehicles.	Legislation