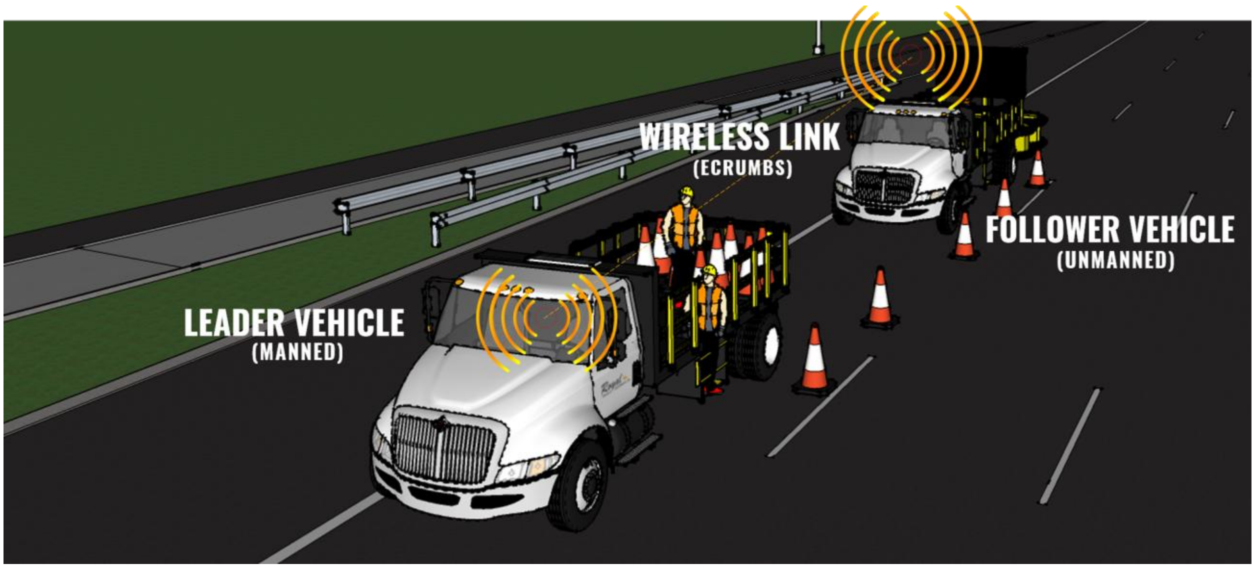
Autonomous Truck Mounted Attenuator (ATMA) Toolkit



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Abbreviations

AASHTO: American Association of State Highway and Transportation Officials
ADT: Average Daily Traffic
AES: Advanced Encryption Standards
AG: Attorney General
AIPV: Autonomous Impact Protection Vehicle.
AMT: Autonomous Maintenance Technology
ATMA: Autonomous Truck Mounted Attenuator
AV: Autonomous Vehicle
AV: Autonomous Vehicle
CAV: Connected and Automated Vehicle
CDOT: Colorado Department of Transportation
COI: Certificate of Insurance
CTE: Cross Track Error
DOR: Department of Revenue
DOT: Department of Transportation
EMS: Emergency Medical Services
FMVSS: Federal Motor Vehicle Safety Standards
GPS: Global Positioning System
GYRO: Gyroscope
HAV: Highly Automated Vehicle
HMI: Human-Machine Interface
IFB: Invitation for Bid
IMU: Inertial Measurement Unit
INS: Inertial Navigation System
JHA: Job Hazard Analysis
KPI: Key Performance Indicator
LIDAR: Light Detection and Ranging
MASH: Manual for Assessing Safety Hardware
MnDOT: Minnesota Department of Transportation
M-PAK: Multi Platform Appliqué Kit
MPH: Miles per Hour
MUTCD: Manual on Uniform Traffic Control Devices
NCHRP: National Cooperative Highway Research Program
OCU: Operator Control Unit
ODOT: Oklahoma Department of Transportation
RAD: Roll Ahead Distance
RF: Radio Frequency
RFP: Request for Proposal
RPM: Revolutions Per Minute
SCU: System Control Unit

SLAM: Simultaneous Localization and Mapping
SMART: Strengthening Mobility and Revolutionizing Transportation
TMA: Truck Mounted Attenuator
TPF: Transportation Pooled Fund
TRB: Transportation Research Board
UI: User Interface
V2V: Vehicle to Vehicle

Document Version

The structured numbering for document version control helps maintain clarity and traceability of updates across the document lifecycle.

Version	Author
1.0	Pennsylvania State University: XB Hu, Yuyan Pan; Colorado DOT: Gagan Masaun, Heather Pickering-Hilgers; Wisconsin DOT: Erin Schwark; Minnesota DOT Adam Wellner; Oklahoma DOT: Alan Stevenson
1.1	Gagan Masaun, Heather Pickering Hilgers

Final Reviewer/approver

Name	Role	Completed Review Date
Heather Pickering-Hilgers	CDOT reviewer	July 25 2025

***Version 1.0** is the first complete and approved release of this document. Subsequent **minor revisions** will be documented as **1.1, 1.2**, etc., indicating updates that may include clarifications, formatting adjustments, or non-substantive edits that do not significantly alter the document's purpose or structure. A change to **Version 2.0** will signify a **major revision**—reflecting substantial modifications, such as new sections, restructured content, or changes that impact the document's overall scope or intent.

Purpose

This Autonomous Truck Mounted Attenuator (ATMA) toolkit is intended to guide agencies through the initial steps of deployment and highlight key considerations for those exploring the implementation of an ATMA system. This toolkit was drawn with direct feedback from the four participating state DOTs: Colorado, Minnesota, Wisconsin and Oklahoma. By providing a comprehensive roadmap, this toolkit is designed to help other State DOTs and agencies to streamline and understand the ATMA deployment process, avoid common pitfalls, and maximize the benefits of ATMA technology.

Disclaimer

This toolkit is intended as a guideline and reference document to assist agencies in planning and implementing ATMA deployments. Each State DOT and organization operates within unique regulatory, procurement, and operational frameworks that should be carefully considered when using this Toolkit. It is strongly recommended that agencies engage with appropriate stakeholders (e.g. state DOT officials, regulatory bodies, and vendors, research institutions) to contextualize and tailor the deployment approach to their specific needs. As a living document, this Toolkit will evolve over time, incorporating new insights, case studies, and best practices as more agencies successfully implement ATMA technology.

Components of this toolkit

- Best practices, strategies, and deployment models for effective ATMA deployment.
- Guidelines for leveraging Toolkit resources to establish a structured deployment plan.
- Lessons learned and documentation from organizations in different Pre-Deployment and Deployment phases.
- Training guidelines to equip personnel with the necessary skills for ATMA operation.
- Assessment and data collection protocols to monitor performance and safety improvements.

Key considerations

Stage 1: Pre-Deployment (discovery and ideation)

Assess the feasibility of ATMA deployment and determine how the technology aligns with the operational needs. Key activities include understanding ATMA technology and its capabilities, conducting stakeholder engagement to build institutional support (including Risk Management, local law enforcement, DOR and AG's office for legal implications), identifying funding sources and grant opportunities, and developing an initial business case for ATMA adoption.

***Please refer to Appendix A for details on the pre-deployment process**.*

Stage 2: Procurement

Once a formal decision is made to acquire ATMA technology, the next step is selecting appropriate procurement methods (e.g., sole-source contracts, competitive bids, public-private partnerships), work with vendors and researchers to ensure system compatibility, and establish necessary regulatory approvals and compliance measures.

Please refer to Appendix B for details on the procurement process

Stage 3: Testing and Validation

Rigorous testing and validation are crucial to the success of the ATMA deployment to confirm system performance, reliability, and safety. This stage involves developing standardized test cases and evaluation procedures, conducting on-site validation under real-world conditions, defining acceptance criteria and performance benchmarks, and addressing potential integration challenges with existing work zone operations.

****Please refer to Appendix C for details on the test plans***

Stage 4: Deployment and Integration

After clearing Stage 3 agencies can move into full-scale deployment. In this stage, agencies identify ATMA operators for training and establish operational protocols, define on-road integration strategies for ATMA in active work zones, monitor system performance metrics and safety outcomes, and document lessons learned to refine best practices.

Please refer to Appendix D for details on the deployment

Key Tasks and Deliverables

It is essential to clearly define the key tasks and their associated deliverables. A few representative tasks are listed below as a starting point; however, each State DOT may use different terminology, scopes, or sequences.

Task 1: System Description and Compliance

Document the proposed system, use cases, stakeholders, cybersecurity protections, V2V communication architecture, fail-safe protocols, and alignment with national AV standards and agency-specific safety policies.

Task 2: Training and Testing Plan Development

Develop detailed plans for training agency staff to operate and manage the ATMA system. The plan should include instructional materials, hands-on practice sessions, and performance assessments to ensure competency.

Task 3: Retrofit and Delivery of Vehicles

Coordinate with the agency to retrofit the provided trucks with ATMA components. The vendor must ensure system integration maintains vehicle safety, warranty, and operational standards.

Task 4: Staff Training Execution

Conduct training programs for State DOT staff in collaboration with agency leads, focusing on safe operation, troubleshooting, and daily system checks.

Task 5: Controlled Environment Testing

Demonstrate system functionality and safety performance in a controlled roadway environment. Where possible, testing may be verified by a third-party evaluator, such as a local university partner.

Task 6: Live Work Zone Deployment

Deploy the ATMA system in an active work zone for a defined period, allowing for real-world validation of system durability, operational readiness, and user feedback.

Key Takeaways – Themes among the States

From deployment experiences across Colorado, Minnesota, Wisconsin, and Oklahoma, several consistent themes emerged:

- Worker safety is the core motivation – Removing the human operator from the most vulnerable vehicle significantly reduces crash-related injury risks.
- Technology requires iteration – Most states encountered reliability and integration issues, especially in early deployments. These challenges were addressed through phased testing and vendor collaboration.
- Partnerships are essential – Successful programs involve collaboration not only with DOT staff but also with academic institutions, vendors, and public safety agencies.
- Use Cases – ATMA performance and safety varied by its application. It was most effective in slow-moving operations like striping, sweeping, and patching.
- Staff training and buy-in are critical – Adoption was smoother when operators were trained early and felt confident in their understanding of system behaviors.

- Procurement can be a bottleneck – Flexible specifications and early involvement of procurement staff helped mitigate contracting delays.

Lessons Learned

- **Design for Serviceability:** Field operability and maintenance readiness are essential for sustained ATMA use. Equipment should be ruggedized for roadside environments and designed with accessibility in mind. States reported challenges with systems featuring non-standard connectors, hidden dashboards, or cramped cab layouts that complicated routine inspection and repairs. Designing with serviceability in mind allows maintenance personnel to quickly troubleshoot and resolve issues without extensive downtime.
- **Expect Communication Interference:** Many ATMA systems rely on 900 MHz radios for vehicle-to-vehicle communication. However, interference from industrial equipment, nearby infrastructure, or radio-saturated environments can compromise signal quality. Several deployments experienced intermittent communication losses that impacted performance. Agencies are advised to plan for redundancy in communication protocols, consider dual-radio setups, and ensure operators are trained to respond appropriately to signal drops.
- **Don't Underestimate GPS Loss:** One of the most common challenges reported by states was the loss of GPS signals in shaded, wooded areas or when passing under overpasses and signage structures. These brief but frequent outages can cause the system to default to backup navigation modes. Robust dead reckoning functionality, inertial navigation, and well-tested A-Stop protocols are essential safeguards. Agencies must also ensure that operators understand the conditions likely to trigger GPS loss and how the system is expected to behave in those scenarios.
- **Emergency systems must be reliable:** Safety is paramount, and the reliability of the emergency stop (E-Stop) and automatic stop (A-Stop) systems cannot be compromised. States emphasized the need for accessible E-Stop buttons inside and outside both the leader and follower vehicles. In some cases, agencies added supplemental external shutoff mechanisms or relocated buttons for better visibility and reach. Redundant safety mechanisms reassured operators and enhanced overall confidence in system integrity.
- **Modularity matters:** Agencies found that modular ATMA design offered distinct operational advantages. Systems that allowed for relatively quick installation, transfer, or reconfiguration between trucks minimized downtime and improved

fleet flexibility. This modularity proved especially useful when integrating ATMA technology into existing equipment procurement cycles or when working with rotating maintenance crews.

- **Involve end users early:** In several deployments, maintenance crews and fleet technicians provided feedback that significantly improved implementation outcomes. Their input shaped key decisions related to vehicle layout, control placement, daily inspection routines, and weatherproofing. Early and continuous involvement of frontline personnel not only ensured practical system design but also promoted buy-in and smoother field adoption.
- **Marketing builds momentum:** Agencies noted that public demonstrations, media coverage, and internal showcase events played a powerful role in securing executive support, community trust, and sustained funding. Seeing the ATMA system in action helped decision-makers and stakeholders understand the safety benefits and technical capabilities, which translated into broader enthusiasm and strategic alignment across departments.
- **Vehicle idling:** If the lead vehicle drops below a certain RPM range (typically 600–900 RPM), some manufacturers may interpret this as idling, causing the vehicle to switch to idle mode. To prevent this, it's important that the paint truck operates in 1st gear, ensuring the engine RPM remains above idle thresholds.
- **Actual deployment:** Before the ATMA can be deployed on roads with live traffic, it's crucial to get the approval from the traffic engineers on the roads which are safe to operate ATMA on. E.g. CDOT deployed the ATMA on roads with Average Daily Traffic (ADT) of 2500 vehicles and then it was increased to 5000 ADT.
- **Maintenance and operations (M&O):** ATMA is not a one-time deployment. Refresher training, vendor support for troubleshooting and replacement parts should be kept in mind and DOTs should have an M&O plan in place for the ATMA.

Appendix A

A1. Pre-deployment: Discovery and ideation

The Discovery and Ideation stage marks the initial phase in the exploration of ATMA technology by State DOTs and other agencies. This stage focuses on gathering information, evaluating feasibility, and conceptualizing potential applications within an agency's operations. At this stage, project discovery and ideation occur simultaneously, as organizations collect technical, operational, and financial insights into ATMA deployment. Agencies begin to define how ATMA fits their specific goals, but at this point, concepts remain in draft form, with no formalized commitment to deployment.

State DOTs typically pursue ATMA technology due to one or both of the following drivers:

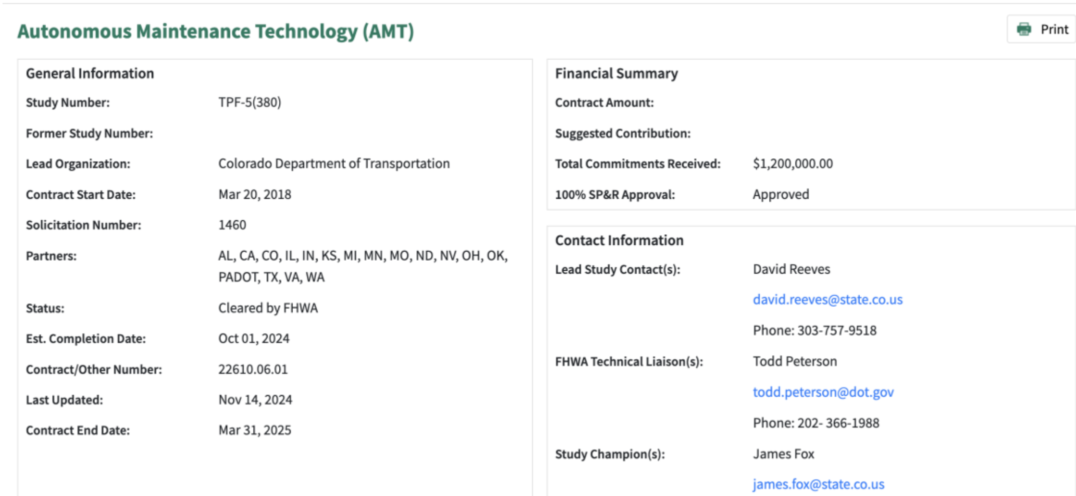
- **Interest in emerging technologies**: Agencies with a strong focus on advanced transportation solutions, including Mobility Technology program (or sometimes called Connected and Autonomous Vehicle (CAV) programs, Office of Transformational Technology, or others), may proactively explore ATMA as part of their broader innovation strategy. Those with dedicated funding, expertise, and resources for automation-related projects are often early adopters.
- **Safety-driven motivation**: Some agencies begin exploring ATMA technology in response to roadway incidents—particularly crashes involving manually operated truck-mounted attenuators. In these situations, ATMA is pursued as a risk-mitigation strategy to enhance the safety of human operators by reducing their exposure to high-risk work zones.

While each state approaches the discovery process differently, several activities are consistently observed:

- Engaging in peer exchanges – Engaging in one-on-one discussions with agencies that have already deployed ATMA to gain insights into their program scope, budget, objectives, and key lessons learned.
- Consulting with vendors – Exploring available ATMA technology solutions, understanding system capabilities, and evaluating potential suppliers.
- Reviewing research – Analyzing existing studies on ATMA to gain insights into system performance, cost-benefit evaluations, and established best practices. This includes reviewing presentations and publications from Transportation

Research Board (TRB) annual meetings, as well as findings from sponsored research projects.

- Connecting with the AMT Pooled Fund – Leveraging knowledge from the AMT Transportation Pooled Fund (TPF) 5(380) to gain insights from multiple agencies.



Autonomous Maintenance Technology (AMT)

Print

General Information

Study Number:	TPF-5(380)
Former Study Number:	
Lead Organization:	Colorado Department of Transportation
Contract Start Date:	Mar 20, 2018
Solicitation Number:	1460
Partners:	AL, CA, CO, IL, IN, KS, MI, MN, MO, ND, NV, OH, OK, PADOT, TX, VA, WA
Status:	Cleared by FHWA
Est. Completion Date:	Oct 01, 2024
Contract/Other Number:	22610.06.01
Last Updated:	Nov 14, 2024
Contract End Date:	Mar 31, 2025

Financial Summary

Contract Amount:	
Suggested Contribution:	
Total Commitments Received:	$1,200,000.00
100% SP&R Approval:	Approved

Contact Information

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Study Champion(s):	James Fox james.fox@state.co.us

Figure 1 Member States and Contact Information of AMT Pooled Fund

Some organizations formalize their initial findings into an early-stage project charter or concept document, even if no official project approval has been granted. These documents typically include:

- Preliminary program vision – Identifying the leading division, potential deployment areas, and intended use cases.
- Deployment scenarios – Drafting possible real-world applications and identifying where the ATMA system could be most beneficial within the agency.
- Market research – Identifying potential ATMA vendors and assessing available procurement options.
- Initial cost-benefit considerations – Outlining potential financial implications, operational efficiencies, and expected safety benefits.

By the end of the discovery and ideation phase, agencies should have a foundational understanding of ATMA's capabilities, deployment challenges, and potential alignment with their goals. This sets the stage for the Project Definition and Scope Refinement phase, where agencies transition from exploration to formalized planning.

A2. Understanding the ATMA Functionalities

This section provides an overview of the ATMA system, helping engineers, transportation agencies, and stakeholders understand its capabilities, limitations, and underlying technologies. The ATMA system is designed to enhance work zone safety by automating the follower vehicle in a TMA pair, removing human operators from hazardous roadside environments.

The key functionalities of ATMA include leader-follower vehicle coordination, autonomous navigation, collision avoidance, emergency response systems, and GPS-independent operation. This section explores how the system operates under normal and GPS-denied conditions, how it ensures safety, and where it has limitations.

At its core, the ATMA system automates the TMA vehicle, following a leader vehicle that is manually driven by a human operator. The system uses V2V (vehicle-to-vehicle) communication, advanced navigation algorithms, and real-time obstacle detection to ensure safe operation. Under normal conditions, ATMA relies on GPS-based navigation, but in environments where GPS signals are lost—such as tunnels, underpasses, or urban canyons—it employs alternative navigation strategies such as Dead Reckoning and LIDAR-based SLAM mapping.

The functionalities of the ATMA system can be divided into several key aspects:

Core functionality #1: Leader-Follower Coordination

The ATMA system operates using a leader-follower vehicle model, in which a human-driven lead vehicle transmits its position, movement commands, and operational status to the autonomous follower vehicle. This behavior is typically supported by e-crumbing technology, which enables the follower to trace the digital path laid by the leader for precise and safe navigation.

- The leader vehicle continuously transmits GPS position data via V2V communication to the follower vehicle (refer to Figure 2 below)

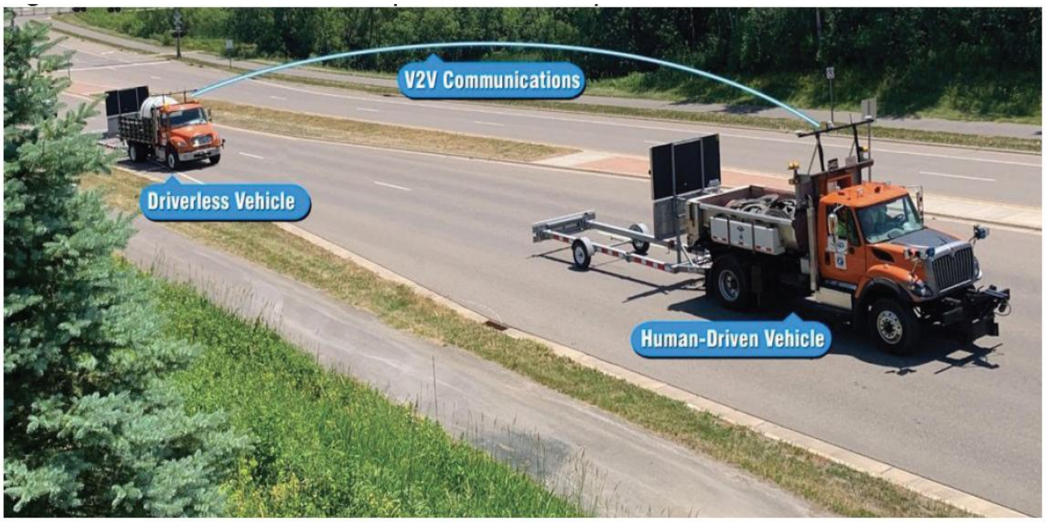

Figure 2 Leader-Follower Setup in the ATMA Operation

- The follower vehicle mirrors the leader's movements, maintaining a pre-set following distance (adjustable from 25 to 1,600 feet) and a lateral offset (adjustable from 0 to 12 feet).
- The leader vehicle operator has access to real-time feedback from the follower vehicle, ensuring situational awareness.

Core functionality #2. Autonomous Navigation and Control

In automated mode, the ATMA system manages the follower vehicle's:

- Steering – Adjusts the wheel based on navigation algorithms.
- Braking – Ensures safe stopping distances and emergency braking when needed.
- Throttle Control – Adjusts speed in response to leader vehicle commands.

Normal operation: Under normal conditions, GPS provides precise positioning for the follower vehicle to track the leader's path. The V2V system ensures the follower vehicle responds in real-time, maintaining lane position and following distance.

Operation in GPS-denied environments: When GPS is unavailable, ATMA switches to Dead Reckoning, using gyroscopes and accelerometers to estimate its position based on previous GPS data. The leader vehicle uses LIDAR-based SLAM mapping to build a real-time 3D environmental map, which is then transmitted to the follower vehicle to assist in navigation. This system ensures the follower vehicle can continue operating safely, even when GPS signals are lost for time spans under a minute.

Core functionality #3: Obstacle detection and collision avoidance

The ATMA system includes multiple sensor layers to detect and avoid obstacles in its path:

- RADAR: Detects large objects and vehicles in front of the follower vehicle.
- LIDAR: Provides precise 3D mapping of surrounding obstacles.
- Ultrasonic sensors: Detect close-range obstacles and potential collisions.

If an obstacle is detected: The system initiates an automatic stop (A-Stop) if it determines that continuing forward is unsafe. If the leader vehicle slows down or stops, the follower vehicle gradually reduces speed to maintain a safe distance.

Core functionality #4: Emergency stop and safety protocols

Safety is a primary function of ATMA, and the system includes multiple redundant emergency stop mechanisms:

- Automatic Stop (A-Stop) – The system automatically stops if it detects a system failure, obstacle, loss of GPS, excessive following distance, or impact.
- Emergency Stop (E-Stop) – A manual override that allows the leader vehicle operator to remotely shut down the follower vehicle immediately.
- Physical E-Stop Buttons – Located inside and outside the follower vehicle, allowing crew members to manually halt operations in an emergency.

The multi-layered redundancy ensures that the ATMA vehicle can always be brought to a controlled stop, preventing accidents and ensuring worker safety.

Core functionality #5: Data logging and system monitoring

To improve work zone safety and efficiency, ATMA continuously collects and records performance data, including:

- Vehicle telemetry – Speed, position, heading, inter-vehicle gap distance.
- System diagnostics – Monitors hardware/software performance and logs any failures or malfunctions.

This data can be used for multiple purposes, such as:

(1) Incident analysis in case of a crash or system failure;

(2) Performance evaluations to refine ATMA operations, and

(3) Regulatory compliance reporting for automated vehicle testing.

Core functionality #6: Cybersecurity and communication security

Because ATMA relies on V2V communication, cybersecurity is a critical concern. To prevent hacking or signal interference, the system employs:

- 128-bit AES encryption for all V2V communications.
- Dual-redundant RF radios to prevent signal loss.
- Frequency hopping to reduce interference from external devices.

This ensures secure, reliable communication between the leader and follower vehicles, preventing unauthorized control or signal disruptions.

A3. Development of the business case

Developing a strong business case is a critical step in the pre-deployment phase of the ATMA system. A well-defined business case helps justify the investment, secure leadership support, align with regulatory requirements, and establish a roadmap for implementation. This section explores the common drivers for adopting ATMA technology, the process of formalizing a business case, and case studies from State DOTs that have successfully developed business cases for ATMA deployment.

Steps in Business Case Development

A structured approach ensures that agencies can effectively communicate the value of ATMA technology to decision-makers, stakeholders, and funding bodies.

Figure 3 Steps in Business Case Development

The first step in business case development is *assessing the safety and operational needs*. Agencies begin by analyzing historical TMA crash data to quantify the risks associated with manual operation. They also review maintenance work zone layouts to identify locations where TMAs are most frequently impacted. In many cases, agencies engage field personnel to gather firsthand insights on work zone safety challenges.

Once the need is established, *a cost-benefit analysis* is conducted. Agencies estimate costs related to vehicle procurement, system integration, and training, then compare these to the potential savings from reduced worker injuries, lower vehicle repair costs, and improved work zone efficiency. Demonstrating a strong return on investment strengthens the case for leadership approval.

Stakeholder engagement is another critical step. Within the DOT, decision-makers from maintenance, operations, legal, and procurement divisions must be involved early to ensure alignment. Agencies may also consult with vendors, researchers, and federal agencies to gain insights into best practices for ATMA deployment.

Regulatory and policy alignment must also be considered. Agencies must evaluate whether current state and federal regulations facilitate or restrict ATMA deployment. In parallel, procurement staff should review vendor selection procedures to ensure alignment with applicable purchasing laws. Legal teams play a key role in assessing potential liability risks and coordinating with insurance providers to clarify coverage requirements and implications.

Many agencies strengthen their business case for ATMA through demonstration projects. Initial testing in controlled environments enables them to assess system performance before transitioning to active work zone deployments. Pilot projects offer real-world validation, allowing agencies to fine-tune operational procedures and gain confidence in the technology. The performance data gathered during these demonstrations also reinforces the justification for broader implementation.

Case Studies from State DOTs

Several state DOTs have successfully developed business cases for ATMA deployment, each taking a slightly different approach based on their unique priorities and circumstances.

- Colorado's Department of Transportation (CDOT) pursued ATMA deployment through its Office of Innovative Mobility. Leadership recognized ATMA's dual benefits of eliminating risk to human operators while demonstrating the state's commitment to autonomous vehicle technology. The business case secured high-level agency support by framing ATMA as an early success story within CDOT's broader automation strategy.

Figure 4 CDOT ATMA project vision

- Minnesota's Department of Transportation (MnDOT) aligned its ATMA initiative with the state's Connected and Automated Vehicles (CAV) Strategic Plan. The business case focused on enhancing work zone safety through automation while also fostering public-private collaboration to advance CAV technology. MnDOT introduced an innovative procurement process, allowing vendors to propose automation solutions in an open, rolling competition rather than through a rigid RFP. This flexible approach enabled industry partnerships and accelerated ATMA evaluation.

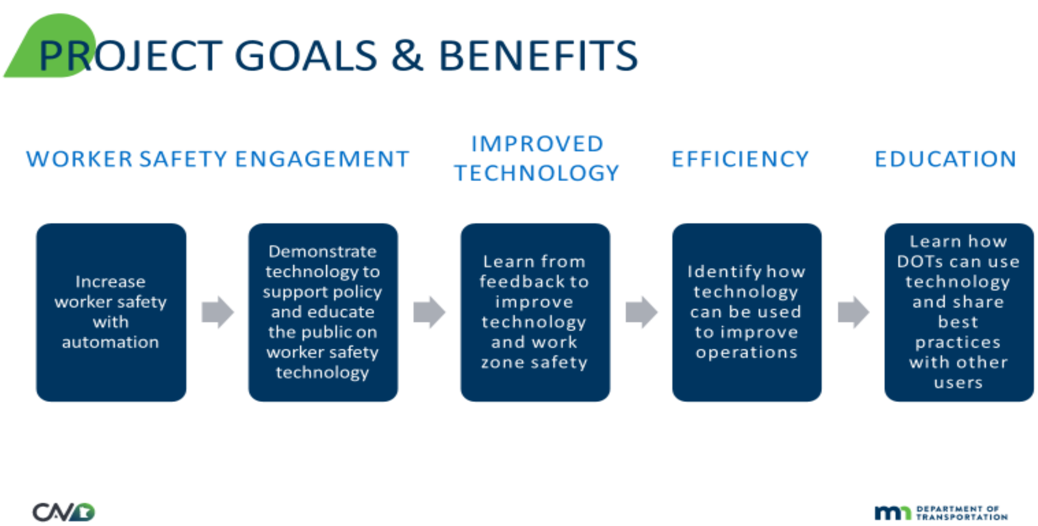

Figure 5 MnDOT ATMA Project goals and benefits

- Wisconsin Department of Transportation (WisDOT) piloted the ATMA with its Bureau of Traffic Operations, Work Zone Program in partnership with the Wisconsin County Highway Association (Dane County). The business case was to gather feedback from the county highway department to determine the ATMA use cases for future deployment. The pilot was conducted over one week, so limited data was gathered.
- Oklahoma Department of Transportation (ODOT) purchased the ATMA through its Maintenance Division's Fleet Management unit. Their business case centered on enhancing work zone safety and boosting efficiency during active field maintenance operations. To maximize the effectiveness of the ATMA, O acquired a standard pickup truck to serve as the lead vehicle, enabling a wide range of maintenance activities to be carried out alongside the ATMA.

A4. Check Regulation alignment

A4.1 Federal Regulations and National Standards

Ensuring compliance with federal regulations and national standards is a critical step in the pre-deployment phase of ATMA technology. The research team conducted a review of key federal guidelines to assess whether ATMA technology aligns with existing policies. Specifically, we examined four major federal documents:

1. Automated Driving Systems: A Vision for Safety 2.0
2. Preparing for the Future of Transportation: Automated Vehicles 3.0
3. Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0
4. Manual on Uniform Traffic Control Devices (MUTCD)

The first three documents, issued by the USDOT and the National Highway Traffic Safety Administration (NHTSA), serve as voluntary guidance rather than mandatory regulations. These documents provide principles for safe AV deployment, recommend best practices, and emphasize the importance of state and industry collaboration. The MUTCD, which governs traffic control devices and roadway safety standards, was also reviewed to determine its implications for ATMA operations in work zones.

Based on our preliminary analysis, no significant conflicts were found between ATMA technology and these federal guidelines. This suggests that, from a federal perspective, deploying ATMA should not pose regulatory challenges. However, it is advisable for State DOTs and agencies to stay informed on emerging federal policies and updates that may impact future deployments.

A4.2 State-Specific Regulations

While ATMA technology does not face significant regulatory obstacles at the federal level, state regulations on AVs vary widely. Each state has its own legislative framework governing AV deployment, creating a complex regulatory landscape (Autonomous-vehicle-statutes-and-regulations-across-the-50-states). State AV statutes can generally be classified into three broad categories:

- States that accommodate the piloting and testing of AV technology – these states have legal provisions that allow controlled testing and piloting of AVs under specific conditions, often requiring human oversight.
- States that approve AV operation once certain regulatory standards are met – These states set future-oriented policies allowing AV deployment once safety and technical requirements (many of which are still under development) are satisfied.
- States without any specific AV statutes – These states lack clear legislation addressing AV operations, leaving legal uncertainty regarding their deployment.

Given this state-by-state variability, it is essential for agencies to review local AV policies before pursuing ATMA deployment. Some states may require additional certifications, safety demonstrations, or legislative approvals before allowing AV-equipped maintenance vehicles to operate on public roads. States with restrictive AV laws may need policy adjustments or exemptions to accommodate ATMA technology. While this Toolkit does not provide state-specific legal templates, it is important to note that changes to AV-related statutes typically require the coordinated effort of multiple stakeholders. Successful legislative advancement often involves a coalition that includes AV technology developers, nonprofit safety advocates, industry associations, state DOTs, legislative leaders, and research universities. For example, Pennsylvania's approach illustrates a model for policy evolution: PennDOT convened a Highly Automated Vehicle (HAV) Advisory Committee comprising diverse stakeholders across sectors to explore policy gaps and regulatory needs HAV Advisory Committee Overview and goals. The committee conducted a series of public meetings and focus groups to gather broad input and ultimately submitted formal written recommendations to the state legislature to inform statutory updates Penn DOT Act 130 Reporting: Evaluating the Impact of Connected and Automated Vehicles to the Commonwealth of Pennsylvania. Similar stakeholder-driven models can be effective in other states, offering a pathway to ensure that ATMA deployments align with both public safety goals and evolving legislative frameworks.

A4.3 Insurance Considerations for ATMA Deployment

Another critical regulatory consideration is insurance coverage for ATMA operations. Most states that permit AV deployment require vehicle liability insurance that meets their minimum coverage standards. However, some states impose additional requirements that could impact ATMA deployment.

For example, certain states mandate higher liability coverage thresholds for autonomous vehicles compared to traditional fleet vehicles. Others require self-insured status, operator certification, or financial responsibility filings before AVs can legally operate. Additionally, states may impose human oversight conditions, requiring remote monitoring or on-site supervisors to intervene in case of system failure.

Because insurance policies for AV operations remain an evolving issue, agencies should work closely with legal teams, insurers, and state regulators to ensure compliance. As AV technology matures, more uniform insurance standards may emerge across the U.S., but for now, agencies must navigate state-specific requirements to establish appropriate liability coverage for ATMA deployments.

A5. Garnering Institutional Support

Securing institutional support across various levels of an organization is a critical factor in the successful initiation and deployment of the ATMA system. From executive leadership to frontline operations staff, building consensus ensures stakeholder buy-in, program feasibility, and smooth integration into existing maintenance and transportation workflows. This section outlines key divisions and units that typically play a role in supporting ATMA projects, as well as common strategies for securing institutional backing. While approaches may vary based on an organization's structure, culture, and decision-making processes, successful deployments have demonstrated the importance of both top-down and bottom-up engagement strategies.

Based on experiences from early adopters, several common divisions or business units have been instrumental in driving institutional support for ATMA technology within State DOTs:

- Divisions of Maintenance and Operations – Most commonly, the divisions of Maintenance and Operations are leading the initial institutional support and feature initial conversations with units that work in the DOT's research program and CAV program
- Division of Research and Innovation – Evaluates emerging transportation technologies and provides technical assessments.
- Office of Innovative Mobility (or, Connected and Automated Vehicle Program, Office of Transformational Technology) – Supports autonomous and connected vehicle initiatives that align with ATMA deployment.
- Division of Equipment – Manages fleet acquisition, vehicle specifications, and integration of new technologies.
- Procurement – Ensures compliance with state purchasing regulations, vendor selection, and contract development.

- Traffic Safety Engineering – Assesses work zone safety impacts and integrates ATMA with broader roadway safety strategies.
- Regional Transportation Directors (Districts/Regions) – Oversees maintenance operations at the district or regional level, ensuring the technology meets on-the-ground operational needs.

Each of these divisions contributes to the feasibility, adoption, and long-term sustainability of ATMA within an agency.

The process of securing institutional backing varies based on the organizational framework, leadership style, and agency culture. Two common approaches are:

1. **Top-Down Approach** – In some organizations, ATMA adoption begins at the executive level, where directors or senior leaders champion the project and direct program staff to initiate deployment efforts. This model often accelerates decision-making by aligning ATMA with broader agency goals and securing high-level funding commitments early in the process.
2. **Bottom-Up Approach** – In other cases, early support originates from program-level staff or regional maintenance teams, who then work to build awareness and secure executive buy-in based on operational feasibility and pilot project success. This approach allows for a more organic adoption process, with input from field operators who will ultimately use the system.

Regardless of the approach, cross-functional collaboration between executives, program staff, and field personnel is essential to ensure a smooth transition from concept to deployment.

Wisconsin and Colorado’s institutional support examples are detailed below.

State: Colorado

Leading Units:

- Director of Maintenance and Operations (executive level)
- State Maintenance Engineer (program/staff level)

Supported by:

- Regional Transportation Directors (districts/regions who conduct maintenance)
- Maintenance and Operations
- Traffic Safety Engineering
- Office of Innovative Mobility
- Research Branch

- Procurement

State: Wisconsin

Leading Units:

- Administrators Office
- Bureau of Traffic Operations
- Division of Budget and Strategic Initiatives

A6. Critical Conversations, Stakeholders, and Participating Organizations

A6.1 Key Internal Conversations

Engaging the right stakeholders—both internal and external—is essential for a successful pre-deployment process. Without proper coordination, misalignment among key decision-makers can delay or even halt ATMA implementation.

Key stakeholders (internal and external) in the department can either make or break the pre-deployment stage. Most significantly, all deployers expressed the need for the Maintenance and Operations division of the organization to have significant involvement, lead and buy-in in the program. This ensures that everyone from the Director or Chief of Maintenance all the way down to the maintenance operator have understanding and appreciation of the value of the ATMA program to the organization's mission. Establishing early internal consensus helps prevent resistance to change and ensures smoother integration into existing operations.

Upon initial buy-in across the organization among those that will be involved in the ATMA program, it is critical to engage with the state DOT's procurement and risk management division to identify all procurement regulations and requirements. Procurement documents and resources are discussed in detail in the following section. DOTs should engage the Department of Revenue on any special provisions required for the licensing of these vehicles and law enforcement for a demo and a test validation. However, many state DOTs noted a major lesson learned in underestimating the involvement and effort entailed in the broader procurement process. The uniqueness of the ATMA's technology may present challenges in the purchase of the technology (purchase of a new fleet vehicle, price of the technology, technology needs (such as software support, etc.).

In addition to procurement, risk management is another key consideration. This is because the autonomous truck may have to be transported across state lines for system installation, integration, testing, or training. It's essential that the Risk Management team review and approve the COI provided by the vendor. Many DOTs expressed early engagement with the procurement division can aid in identifying issues that should be promptly addressed. DOTs have found that early engagement with procurement and risk management teams helps identify potential issues that can be addressed proactively, reducing delays in program initiation.

A6.2 External Stakeholders

In addition to internal coordination, agencies must work closely with state agencies, private sector partners, and the academic community to ensure comprehensive planning and deployment of an ATMA program. The following stakeholders have been identified as critical external partners based on the experiences of multiple state DOTs. If a stakeholder was only mentioned by a single DOT, it is specifically noted.

- State Agencies: Coordination with executive leadership (Governor's Office), state patrol, regulatory agencies, and tollway authorities is necessary to navigate AV regulations and enforcement policies.
- Local Partner Universities: Academic institutions provide research support, testing environments, and independent evaluations of ATMA technology. Partner universities can sometimes assist with reviewing the state of the practice and understanding the potential challenges of deploying technology under the state's unique conditions, such as weather, terrain, or state-specific regulations.
- Consultant Support and Marketing: Some agencies, such as MnDOT, engaged external consultants to help educate internal leaders and frontline staff on the benefits and operational implications of ATMA technology.
- Maintenance Contractors: Coordination with third-party contractors is essential, particularly in states where highway maintenance operations are outsourced. Ensuring that contractors understand ATMA's capabilities and integration requirements facilitates a smoother transition into existing maintenance workflows.

By actively engaging both internal and external stakeholders, agencies can establish a strong foundation for ATMA deployment, ensuring that regulatory, technical, and operational challenges are addressed in the early planning stages.

A7. Role of a Demonstration

Many state DOTs held or sponsored ATMA technology demonstrations to build momentum and gain support from key stakeholders. States noted that these demonstrations significantly accelerated adoption, as stakeholders could witness the technology firsthand, transforming it from an abstract idea into a tangible solution.

Gaining trust in emerging technologies can be challenging when they haven't been widely deployed, making early exposure essential. Several DOTs shared that the demonstrations sparked strong stakeholder enthusiasm, allowing them to experience the system up close and start envisioning its impact on their programs.

A7.1 Colorado's Demonstration

In August 2018, CDOT hosted the first public demonstration of the ATMA on a public street located within the Colorado State University campus in Fort Collins, Colorado. The event allowed CDOT the opportunity to officially unveil and publicly announce their first-of-its-kind ATMA in the CDOT fleet. The event featured a press conference with representatives from CDOT, the federal government and all project partners (Royal Truck, Kratos, City of Fort Collins, and Colorado State University), as well as a demonstration of the ATMA in action during a live roadway striping operation. CDOT offered a livestream of the ATMA demonstration on CDOT's Facebook page and YouTube as well. The public demonstration offered CDOT the ability to inform the public on the operation of the ATMA and garner statewide enthusiasm on leveraging innovative technology in Colorado to improve safety. Prior to the public demonstration, CDOT staff and partners did conduct significant closed course testing, verification, and validation of the CDOT's ATMA.

CDOT reported the following outcomes from their public demonstration:

- Officially announced and unveiled the innovative ATMA technology within CDOT's fleet
- Educated the public about the vehicle's deployment on Colorado roadways
- Boosted statewide excitement for innovative technologies, further fueling interest in the ATMA program both within Colorado and across the nation
- Strengthened CDOT's position as a leader in deploying ATMA technology

A7.2 Wisconsin's Demonstration

In May 2025, the Autonomous Truck Mounted Attenuator (AMTA) demonstration project was completed in Dane County, Wisconsin. The demonstration aimed to test the feasibility and safety benefits of using the driverless ATMA during mobile pavement marking operations. The demonstration began with a couple hours of in-classroom training with Kratos Defense and employees from the Dane County Highway Department marking crew followed by closed-road testing to assess system performance in a controlled environment. Subsequent open road testing involved real-world scenarios to evaluate the ATMA's effectiveness in providing crash protection without a human driver on board. The pilot concluded with a demonstration for upper management and stakeholders from various business areas to showcase the technology's potential in enhancing worker safety and operational efficiency.

While the ATMA showed promising results during testing, certain limitations were identified for its deployment on two-lane conventional highways and high-volume roadways. Current law requires the presence of a safety driver, which restricts full automation benefits. However, the system has significant potential on multi-lane roads. Despite the constraints, the ATMA demonstrated advanced navigational capabilities by proceeding through roundabouts, controlled intersections, U-turns and right angle turns during testing. These results highlight the system's ability to handle complex driving environments and dynamic traffic conditions. Continued refinement of both technology and related regulatory frameworks could pave the way for broader deployment, especially in environments where its protective role can significantly enhance worker safety without impeding traffic flow.

The pilot was deemed successful overall and received mostly positive feedback from the workers involved in the operations. Participants expressed confidence in the ATMA systems ability to enhance safety by removing personnel from the most hazardous positions. However, one notable piece of feedback concerned the lack of backing capabilities of the follower vehicle which limited flexibility during certain operational setups or repositioning maneuvers. Addressing this limitation in future iterations could further improve the system's usability and efficiency in diverse roadway environments.

A8. Project Definition and Scope Refinement

As agencies move from early ideation to formal planning, the Project Definition and Scope Refinement phase helps transition ATMA deployment from concept to implementation. In this stage, agencies develop a clearly defined deployment strategy, scope of work, project team, and organizational home responsible for managing the project.

A8.1 Scope of Work

Defining the scope of work is an essential milestone in planning an ATMA deployment. This section establishes what services the technology provider is expected to deliver, under what conditions, and in coordination with which agency-provided resources. A clear and comprehensive scope ensures expectation alignment between the agency and technology provider, and helps manage risk, cost, and performance throughout the project lifecycle.

A8.2 Service Expectations

The service scope typically includes the delivery of a fully functional autonomous leader-follower truck-mounted attenuator system for use in mobile highway work zone operations. The system is expected to function in compliance with nationally recognized guidelines for maintenance vehicle safety, including applicable crashworthiness standards and technical specifications.

The system configuration will vary depending on the agency's procurement strategy. In many cases, the State DOT will provide the base trucks and TMAs from its existing fleet, while others may opt to procure new vehicles. The technology provider will be responsible for integrating the ATMA system—including all sensors, communication systems, automation components, and control interfaces—into these agency-owned vehicles.

Work zone operating speeds are typically under 15 mph, while transportation to and from the work zone will occur under manual operation. The system must support safe transition between autonomous and manual driving modes and provide reliable performance during low-speed operations in active maintenance zones.

A8.3 Use Cases and Compliance Requirements

To ensure operational relevance and real-world applicability, agencies must define the specific use cases for ATMA deployment. This may include pavement striping operations, sweeping, pothole patching, and other mobile maintenance activities requiring a trailing safety vehicle. Acceptance criteria should be established for system readiness, safety validation, performance reliability, and operator usability.

Each deployment must comply with relevant national standards, including crashworthiness e.g., NCHRP 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features NCHRP Report 350, or Manual for Assessing Safety Hardware (MASH) Manual for Assessing Safety Hardware, automated vehicle safety guidelines, and any applicable state regulations. Vendors should be required to ensure that system integration does not void the manufacturer's warranty of the host vehicle and that any damages caused by technology installation are fully addressed.

A8.4 Truck Fleet and Equipment Information

State DOTs should clearly identify the trucks available for retrofitting, including make, model, year, and mileage. This information helps vendors assess integration needs and compatibility. Contact information for the Division of Equipment or relevant fleet coordinators should be included to support pre-installation coordination.

A9. Project Team

The success of an ATMA deployment depends on cross-functional collaboration among internal divisions, executive leadership, and external partners. Agencies should formally designate a project team with clearly defined roles and responsibilities across the full deployment lifecycle.

A9.1 Agency Leads and Core Divisions

On the State DOT side, the Division of Maintenance and Operations and/or the CAV Program typically act as the project champions. Leadership is usually provided by the Director of Maintenance and Operations and/or the CAV Program at the executive level, along with the State Maintenance Engineer at the program or staff level. These leaders guide strategic planning and ensure the project aligns with the agency's overall goals. Other essential internal partners include:

- Division of Research and Innovation
- Procurement Office
- Division of Equipment
- Risk Management Division
- Traffic Safety Engineering
- Regional Transportation Directors (Districts/Regions)

A9.2 Leadership

Institutional backing from executive leadership is equally essential. Involvement from the Governor's Office, State Patrol, and regulatory agencies helps secure broader alignment with public safety priorities, regulatory requirements, and long-term innovation strategies.

A9.3 Academic and Research Partners

Partnering with local universities or research institutions can provide valuable third-party support for testing, performance validation, data analysis, and independent evaluation. These partnerships also offer opportunities for innovation, workforce development, and shared learning.

Appendix B: Procurement

This section outlines how to structure an ATMA procurement program, collaborate across divisions, define program vision, and prepare for vehicle arrival.

B1. Procurement

Upon developing a strong business case and securing organizational support, agencies can begin the procurement process for an ATMA system. This process varies across states, depending on each DOT's internal procurement rules, approval pathways, and funding availability. Regardless of the pathway, a common feature across all deployments is the need to develop a comprehensive technical specification to guide the purchase and ensure the solution meets agency needs.

States have taken two general approaches to procurement:

1. **Direct procurement by the State DOT**: This approach often includes support from a university partner to assist with specification development and testing. It can be further categorized into sole source purchases and open bidding through Requests for Proposals (RFPs). CDOT took this approach for their ATMA deployment.
2. **Procurement through a university partner**: California (Caltrans) took this approach, where the University of California handled the purchase and supported evaluation activities.

B2. Program Setup

B2.1 Division Coordination

Effective ATMA procurement requires **coordination across multiple internal divisions** within the State DOT. The Maintenance and Operations division (or the CAV Program) often leads the effort, but additional coordination is needed with:

- **Procurement Office** – for vendor solicitation and contract execution.
- **Division of Equipment** – to coordinate vehicle specification, availability, and readiness.
- **Risk Management** – for insurance and liability review.
- **Office of Innovative Mobility or CAV Program** – for alignment with automation and emerging tech initiatives.

- **Research Division** – to support technical evaluation, validation, and documentation.

Engaging these units early ensures a shared understanding of the procurement goals and accelerates issue resolution during the contracting process.

B2.2 Program Visioning

Before initiating procurement, many agencies convene a visioning process to align leadership, staff, and partners on key program goals. These may include:

- Enhancing work zone safety
- Demonstrating leadership in automation
- Aligning with statewide innovation strategies
- Supporting data-driven evaluation through partnerships

Establishing a clear, shared vision helps communicate purpose across stakeholders and ensures that the specification reflects long-term agency goals.

B3. Timeline

Procurement timelines differ by state, influenced by the chosen procurement method and internal review procedures. For instance:

1. Sole source purchases can proceed more quickly, often taking around 4 months from initiation to contract execution.
2. RFP-based processes generally take longer, potentially 10 months or more, particularly when multiple solicitations are needed.
3. University-managed procurements typically require about 5 to 6 months to issue a purchase order.

The table below summarizes procurement activities across states, including procurement methods, estimated timelines, and funding sources. These timelines reflect the duration from initial scoping to contract execution, not including vehicle delivery and integration.

State	Good or Service	Procurement Method	Procurement Timeline Estimate	Funding source(s)
Colorado *(Purchase 1)*	ATMA Leader-Follower Kit (includes TMA vehicle)	Sole source	4 months	State DOT funds
Colorado *(Purchase 2)*	Service package – NextGen Upgrade	Sole source (approved in 2017) – quote request	4 months	State DOT funds
CDOT *(Purchase 3)*	ATMA Leader-Follower Kit only	Sole source	4 months	State DOT funds
CDOT *(Purchase 4)*	2 Leader kits and one ATMA kit	Invitation for Bid	8 months	Federal 2022 SMART Grant
Minnesota	ATMA Leader-Follower Kit (includes TMA vehicle)	Open RFP	29 months (delays due to COVID)	State DOT funds
Wisconsin	ATMA Lease	Sole Source	1 month	State DOT Funds
Oklahoma	ATMA Leader -Follower Kit (includes TMA vehicle)	Sole Source	4 months	State DOT Funds

B4. Preparation for departure and arrival of the ATMA

If the vendor is out of state then DOTs should check with their AG's office on what are the requirements for sending State vehicles out of state (insurance and liability). In addition to that, DOTs must carefully assess pickup logistics, including the potential need for specialized equipment—such as flatbed lift trucks—to ensure the safe and secure loading of the vehicle onto the trailer.

Once a contract is executed and the ATMA system is ready for arrival, agencies should begin preparing to receive and inspect the delivered vehicle. Early planning is critical to ensure a smooth transition from procurement to field deployment, and it helps avoid delays that can arise from logistical oversights, resource conflicts, or lack of readiness. Several key activities should be initiated in parallel to streamline the process and maintain project momentum.

Agencies should start by identifying and confirming the physical location where the ATMA system will be delivered. This includes ensuring the site has sufficient space and infrastructure for unloading, inspecting, and, if necessary, temporarily storing the vehicle. If the agency is supplying its own trucks and TMAs, coordination is needed to confirm these units are available and ready for integration with the ATMA system. Lead times for obtaining or preparing vehicles from existing fleets can vary, so early action is essential.

Next, coordination with the Division of Equipment becomes critical. This team typically oversees installation and retrofit activities, including mounting of automation hardware, sensors, antennas, actuators, and V2V communication systems. The installation schedule should align with vendor availability and ensure adequate staffing and shop resources are allocated for the task.

Simultaneously, provisions should be made to conduct training sessions and to deliver all relevant supporting documentation. Agencies should confirm with vendors that comprehensive training materials—such as user manuals, quick-start guides, and troubleshooting instructions are included with the delivery. Hands-on, in-person training for operators and maintenance staff should be scheduled shortly after arrival to build operational familiarity with the system.

*Each trainee should receive a training certificate indicating that they have successfully completed the ATMA training

In summary, effectively preparing for the ATMA's departure and arrival requires proactive communication and coordination among internal teams, vendor partners, and field personnel. Clearly defining roles, responsibilities, and timelines from the outset is essential to ensure smooth delivery, inspection, installation, and training—ultimately enabling timely testing and deployment.

Arrival of the ATMA

When the ATMA system arrives on-site, agencies typically initiate a structured review and onboarding process to ensure the system is ready for integration into their fleet and operations. This multi-step process helps confirm that the vehicle and its components meet all contractual, technical, and safety expectations before it advances to field testing and deployment.

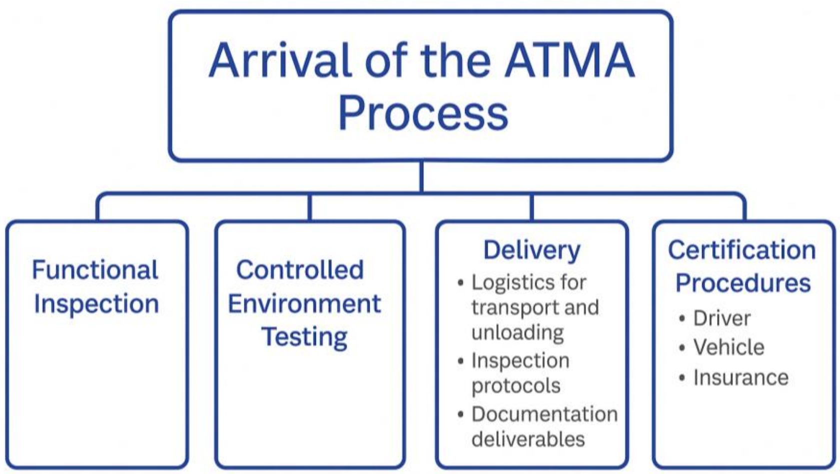

Figure 7 ATMA Arrival Process

A detailed functional inspection must be performed to verify that all hardware, software, sensors, and system integrations conform to the specifications outlined in the procurement documents. The inspection is often conducted in collaboration with the vendor and the agency's fleet services or equipment division.

Prior to deployment in a live work zone, agencies typically schedule controlled environment testing, such as closed-course or non-operational roadway evaluations. These serve as a final verification stage to test system safety features—like A-Stop, E-Stop, and obstacle detection—under agency-supervised conditions.

In addition to operational checks, certification procedures in the next section are a key part of this phase.

B4.1 Driver Certification

All agency operators must complete manufacturer training and obtain certification before operating the ATMA. Certification records are typically maintained in the agency's Learning Management System.

B4.2 Vehicle Certification

The ATMA platform is typically a commercially available TMA truck outfitted with additional automation equipment. For instance, Colorado's ATMA vehicles included a 2017 Hino 338 and a 2020 International MV607. Despite these modifications, the trucks continue to meet all applicable Federal Motor Vehicle Safety Standards (FMVSS). This is because the added systems—such as sensors, actuators, and radios—do not interfere with or disable standard vehicle functions.

B4.3 Insurance Certification

Insurance certification and liability review are coordinated with the agency's Risk Management Division. For example, CDOT maintains proof of coverage, and its Risk Management team ensures all Certificate of Insurance (COI) requirements are met.

B5. Exemplary Procurement Activities

In this section, we provide several examples to illustrate the procurement activities that need to be undertaken when purchasing ATMA technology.

B5.1 CDOT Procurement 1: ATMA Vehicle and Leader Follower Kit (2017 – 2018)

Colorado has undertaken three individual procurements for their ATMA program. The first procurement was the purchase of the ATMA leader and follower kit. The second procurement was for a service agreement for hardware and software updates to the ATMA leader-follower kit. The third procurement is for purchase of one ATMA and two leader kits.

Colorado's first procurement featured a sole source procurement as only one vendor was available in the marketplace for the build and development of an ATMA.

CDOT requested and received a quote from Royal Truck in 2017. Upon receiving the quote, ATMA program staff initiated the sole source procurement process, which involved coordination with both the Division of Procurement and the Division of Audit.

The CDOT Division of Audit team is required to review the full sole source package for fair and reasonable cost review in accordance with the CDOT Procurement Operations Manual. The comprehensive package prepared by the ATMA program staff for the CDOT audit team included the following components:

- Sole source request memo
- Sole source justification form
- Price analysis with Royal Truck's price quotation for comparable costs and assessment of fair and reasonable pricing per Colorado's Fiscal Rules, which included the specification from Kratos
- Royal price quote
- CDOT's truck mounted attenuator minimum specifications

B5.2 CDOT Procurement 2: ATMA System Upgrade and Service Agreement (2018)

In 2018, CDOT utilized the procurement process to perform a hardware and software system upgrade and initiate a service agreement with the vendor to cover the costs of unanticipated troubleshooting and support. Program staff were able to utilize the previously approved sole source for their system upgrade purchase. Staff was required to update the sole source justification paperwork (document provided in Appendix E).

B5.3 CDOT SMART Procurement

CDOT did IFB for this grant and we only got Kratos's response. CDOT ATMA IFB

B5.4 Wisconsin Procurement

The first procurement process in WisDOT was for leasing of the ATMA leader vehicle and the ATMA follower kit. Wisconsin's first procurement featured a sole source procurement as only one vendor was available in the marketplace for the leasing of the ATMA. WisDOT requested and received a quote from Kratos Defense in 2025. Upon receiving the quote, program staff initiated the sole source process. The agreement was finalized and signed within two months of submitting the completed documentation. This process took less than one week for signatures.

Overall the ATMA leasing process was pretty straightforward since the total dollar amount was less than $50,000 and did not require the Secretary's signature.

B6. Procurement Major Lessons Learned

Several important insights have been gained from the initial ATMA procurement activities. We compiled the following lessons learned based on feedback from the participating agencies:

- Early engagement with procurement staff is critical to identify approval requirements and timeline constraints.
- Sole source justification requires thorough documentation, including market research, cost comparisons, and technical specifications.
- University partnerships can sometimes accelerate procurement in states where direct purchasing may face constraints.
- Specification development should involve input from equipment, safety, and legal teams to ensure completeness and compliance.
- Clear coordination between program staff, procurement offices, and risk management can help prevent administrative delays.

Appendix C

C1. Testing and Validation

Testing and quality assurance supports DOT engineers in evaluating the capabilities of the ATMA system. It includes a comprehensive set of defined test cases, procedures for performing these tests, expected outcomes, and the necessary tools to perform statistical analysis and draw meaningful conclusions.

C2.Test cases

Each ATMA use case presents a unique operational and safety challenge, and therefore requires a tailored set of test cases to verify the ATMA system's performance under those specific conditions.

The test cases described below serve as a foundational repository that agencies may select from based on their operational needs. These test cases are not exhaustive but offer a robust starting point for developing a state-specific validation plan. Agencies are encouraged to adapt and expand these test cases in collaboration with vendors, research partners, and field operators.

1. Communication Resilience

- **Simulate RF Loss**: Simulates the loss of radio frequency communication between vehicles to ensure the system can respond appropriately. This is important because V2V communication is essential for the follower vehicle's autonomous operation.
- **Loss of Communication (Single/Double V2V Radios)**: Tests how the system reacts to failure of either the primary or both redundant radios. Validating these scenarios ensures the system has adequate fail-safes.
- **GPS-Denied Environment**: Evaluates the system's ability to operate in tunnels, underpasses, or other areas where GPS signals are lost. This is crucial to assess the performance of dead reckoning or SLAM-based navigation.

2. Follow Distance and Accuracy

- **Follow Distance Set by UI**: Verifies that operators can reliably set and maintain a desired following distance using the user interface. Proper distance control is critical for safety and functional operation.

- **Following Accuracy (Straightaways, Curves)**: Assesses how well the follower vehicle maintains its path behind the leader on straight and curved roadways. Poor accuracy could result in lane departures or unsafe maneuvers.
- **Lane Change**: Tests the system's ability to adapt when the lead vehicle changes lanes. This is essential for dynamic highway environments.
- **Roundabout**: Validates navigation through circular intersections, which are more complex due to continuous turning and entry/exit decisions.
- **Minimum Turn Radius**: Determines the tightest curve the follower vehicle can accurately track, important for urban or constrained environments.
- **U-turn**: Tests the system's capacity to safely perform a full directional reversal while maintaining autonomous coordination.
- **Bump Test**: Ensures the vehicle can navigate over minor surface irregularities without triggering emergency responses or losing track of the leader.

3. Obstacle Detection and Emergency Handling

- **Front View Collision Avoidance**: Validates detection and avoidance of obstacles in the forward path using radar, LiDAR, or camera systems. This is essential for preventing crashes.
- **Side View Object Detection**: Assesses whether the system can detect adjacent obstacles, such as passing vehicles or pedestrians. This enhances situational awareness.
- **Emergency Stops (Internal/External Buttons)**: Confirms that emergency stop buttons inside and outside the vehicle function correctly, enabling immediate shutdown in emergencies.
- **Simulated Rear Impact**: Simulates a crash from behind to trigger appropriate emergency protocols, including system shutdown and alerting.
- **Braking by Lead Vehicle**: Evaluates how quickly and accurately the follower vehicle responds to deceleration by the leader, preventing rear-end collisions.

4. Operational System Components

- **Visual Inspections (System and Trucks)**: Routine check for all visible components to ensure physical integrity and readiness before operation.

- **Arrow Panel and Turn Signals Coordination**: Validates synchronization between the leader and follower vehicle's visual indicators, which are crucial for clear signaling to surrounding traffic.
- **UI Tablet Functionality**: Ensures the user interface is fully operational, intuitive, and displays accurate system status, including gap and lateral offset.

5. Fallback and Recovery

- **Temporarily "Drop" the Follower**: Simulates a scenario where the follower loses the lead vehicle momentarily and must reacquire it. Ensures system recovery and safe resumption of autonomous following.
- **ATMA Operated by a Human Driver**: Confirms that manual override is seamless and safe, which is necessary for non-autonomous travel segments.
- **Emergency Disengagement**: Verifies that an operator can instantly disengage the automation in case of malfunction or hazard.

6. Administrative/Test Completeness

- **Warranty Check**: Ensures all installed hardware and software comply with warranty conditions and vendor accountability agreements.

Each of these test cases should be repeated three times under consistent conditions to verify repeatability and statistical significance. Results should be recorded using GPS logs, onboard diagnostics, and video footage for post-analysis. These procedures ensure that the ATMA system meets performance expectations before full deployment in a live work zone.

C3. Acceptance criteria

After defining the test cases, the next vital step is to develop acceptance criteria—clear standards that determine whether the ATMA system fulfills the requirements of each test. Acceptance criteria must be documented prior to testing and shared with all parties involved. These benchmarks are essential for making go/no-go decisions regarding live work zone implementation and for maintaining consistency and transparency across various agency deployments. The criteria should be developed jointly, with input from the technology vendor, DOT engineers, and academic or research partners involved in the testing process. They must strike a balance between being strict enough to ensure safety and performance, while also being flexible enough to account for the diverse conditions in which the system may operate.

A test is deemed successful only when the ATMA system reliably meets the established acceptance thresholds across multiple test iterations. Any failed tests should be collaboratively analyzed to determine the root causes and to guide necessary refinements before proceeding with further deployment.

Acceptance criteria typically fall into the following categories:

- **Operational Accuracy**: The ATMA must maintain acceptable cross-track error (CTE) during autonomous operation. A commonly applied threshold is ±6 inches deviation from the intended path under standard road conditions. This ensures the follower vehicle maintains lane discipline and does not pose a hazard to adjacent traffic or infrastructure.
- **System Responsiveness**: The ATMA must demonstrate the ability to react to sudden events, such as the abrupt braking of the leader vehicle or loss of communication. Response time should fall within predefined limits to ensure safe following behavior and avoid collisions.
- **Emergency Procedures**: Both automatic and manual emergency stop systems must be fully functional. This includes A-Stop, which triggers a controlled stop in response to sensor failures or communication loss, and E-Stop, which allows for an immediate stop via physical buttons or remote control. A-Stop responds to unsafe conditions with a gradual stop, while E-Stop halts the system instantly. These safety mechanisms are essential to ensure the system can be safely stopped in emergency situations.
- **Obstacle Detection and Avoidance**: The system must accurately detect and respond to static and dynamic obstacles in its forward and lateral paths using LiDAR, radar, or ultrasonic sensors. Acceptance is typically based on successful recognition and response in multiple scenarios, such as cone-sized objects or simulated pedestrian intrusions.
- **GPS and RF Resilience**: The ATMA must maintain operational performance during periods of partial or complete GPS outage and radio frequency loss. Testing should confirm the system can revert to dead reckoning or SLAM-based navigation within a specified accuracy window.
- **Interface Reliability**: The Human-Machine Interface (HMI), including tablet-based controls and displays, must correctly reflect system status, allow for intuitive input, and remain stable during operation. Operators should be able to easily adjust following distances, lateral offsets, and trigger safety actions as needed.

- **Training and Usability**: System operation must be intuitive enough to allow successful use by trained DOT staff. This includes understanding of the UI, safety protocols, and handoff between manual and automated control modes. Acceptance may involve operator certification or completion of a training module.

C4. Develop testing procedures

A robust and structured testing procedure is essential for validating the ATMA system in both controlled and real-world conditions. This procedure outlines how each test case should be executed, including setting, frequency, data collection, and safety protocols.

Controlled Environment Testing Controlled tests are typically conducted in a test track or closed facility where scenarios can be carefully simulated. The controlled environment enables precise replication of test cases and repeatable conditions.

- **Setup**: Define lanes using cones, simulate roundabouts, add speed bumps, and place mock obstacles to create diverse road conditions.
- **Repetition**: Each test case should be executed at least three times to ensure result consistency and statistical significance.
- **Data Collection**: GPS logs, video recordings, and onboard telemetry must be collected for post-test analysis.
- **Operator Roles**: Only certified operators or safety drivers should participate. A safety vehicle should be on standby in all scenarios.

Live Work Zone Testing After successful completion of controlled environment testing, the system can be evaluated under live operational conditions.

- **Conditions**: Tests should be conducted under favorable weather conditions (e.g., clear skies, dry pavement), on flat roadways, and with low-speed limits.
- **Setup**: Select a real work zone task (e.g., striping or sweeping) with support from maintenance personnel. ATMA must follow a lead vehicle and operate in traffic with full safety precautions.
- **Monitoring**: Data should be collected continuously. Operators must conduct real-time monitoring of HMI and system behavior.
- **Duration**: Live deployments may span several days or weeks. Data should be logged and reviewed in 24-hour cycles to identify trends or anomalies.

Documentation and Logging

- All test events should be logged using standardized templates.

- Any deviations or unexpected behaviors should be documented.
- Pre- and post-test inspections should be conducted on the vehicle systems to ensure reliability.

Safety Protocols

- A designated safety lead should be present for every test.
- Emergency stops should be tested at the beginning of each day's testing.
- Communication plans must be in place for immediate shutdown in the event of a malfunction.
- The procedures above ensure that the ATMA system is thoroughly vetted in a range of conditions, providing decision-makers with high confidence in system readiness prior to full deployment.

C5. Develop evaluation procedures and methodology

Once testing has been completed, a structured evaluation methodology must be applied to determine whether the ATMA system meets the defined performance and safety standards. The evaluation process should rely on both quantitative data (example shown in the Figure below) analysis and qualitative observations collected during testing.

TIMESTAMP	VEH	CRUMB	STAMP	LAT	LON	ALT	HEADING	HDG (Desired)	VELOCITY	VEL (Desired)	GAP	GAP (Desired)	#SATS	VALID	CTE	ACCEL	STEER	STATE
12:29:08.9	FLW	0	18290890	38.69359	-93.2615	233.84	103.473	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.0	FLW	0	18290900	38.69359	-93.2615	233.84	103.463	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.1	FLW	0	18290910	38.69359	-93.2615	233.842	103.443	105.085	0.01	3.97	28.48	30.5	23	1	0	-100	0	IDLE
12:29:09.2	FLW	0	18290920	38.69359	-93.2615	233.842	103.523	105.085	0.01	3.97	28.48	30.5	23	1	0	-100	0	IDLE
12:29:09.3	FLW	0	18290930	38.69359	-93.2615	233.84	103.513	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.4	FLW	0	18290940	38.69359	-93.2615	233.84	103.473	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.5	FLW	0	18290950	38.69359	-93.2615	233.838	103.483	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.6	FLW	0	18290960	38.69359	-93.2615	233.837	103.453	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.7	FLW	0	18290970	38.69359	-93.2615	233.839	103.463	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE
12:29:09.8	FLW	0	18290980	38.69359	-93.2615	233.838	103.473	105.085	0.01	3.97	28.48	30.5	19	1	0	-100	0	IDLE

Figure 8: Example ATMA data

1. Statistical Analysis of Performance Data**.** All data collected from the GPS logs, sensor outputs, and UI interactions should be processed to extract key performance indicators (KPIs). These typically include:

- **Cross-Track Error (CTE)**: Measures lateral deviation from the intended path.
- **Inter-vehicle Gap Consistency**: Tracks whether the ATMA maintains a consistent distance behind the lead vehicle.
- **Response Time**: Time elapsed from a trigger event (e.g., lead vehicle braking) to ATMA reaction.
- **Emergency Stop Activation Frequency**: Number and types of E-Stop or A-Stop activations, including false positives.

Descriptive statistics such as mean, median, standard deviation, minimum/maximum values, and quantiles should be calculated for each KPI. These help identify whether system behavior is stable and predictable under repeated conditions.

2. Frequency Distribution and Probability Assessment. The distribution of performance metrics like CTE or obstacle detection success rates can offer insights into variability and reliability. Visual tools such as histograms, boxplots, and scatter plots are useful for quickly identifying outliers and trends.

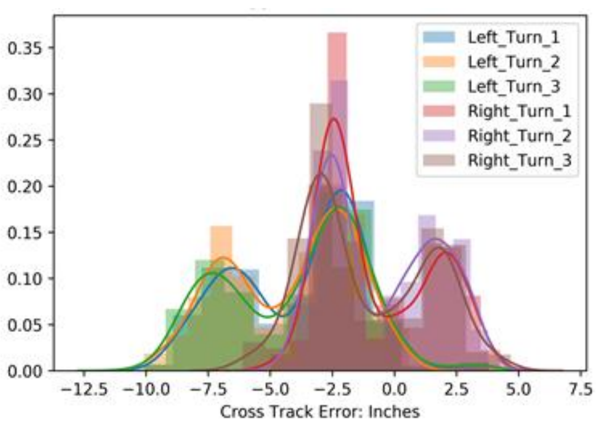

Figure 9: Example Analysis of Cross-Track Error Frequency Distribution

3. Hypothesis Testing for Repeatability. To ensure consistent system behavior across repeated test runs, hypothesis tests like the Friedman Test can be employed. This non-parametric test determines whether multiple related samples come from the same distribution. If results are statistically indistinguishable across trials, it indicates robust and repeatable performance.

4. System Performance Validation. Each test case should be compared against the predefined acceptance criteria. The results must clearly state whether the system **passed or failed** each individual test case. When a failure occurs, the evaluation should document:

- **Nature of the failure:** Clearly describe what aspect of the test failed. This may include system behavior that did not match expected outcomes, hardware malfunctions, communication errors between the leader and follower vehicles, or inaccurate sensor readings. Precise identification of the failure mode is important for corrective action planning.
- **Context of the failure:** Provide background on the conditions under which the failure occurred. This may involve environmental factors such as temperature or weather; roadway characteristics like surface type or geometry; or procedural

context such as whether a manual override was engaged or if the error involved an operator misstep. Understanding the situational context helps distinguish systemic issues from isolated incidents.

- **Diagnostic data:** Include relevant technical data from the vehicle or system logs that support analysis of the failure. This might involve time-stamped sensor readings, actuator commands, GPS positioning data, or error codes generated by the onboard control unit. Collecting diagnostic data allows engineers to trace the cause of the problem and identify trends across multiple test runs.
- **Recommendations for retesting or corrective actions:** Offer guidance on the next steps needed to address the failure. This could include recalibrating equipment, modifying software parameters, repeating the test under more controlled conditions, or conducting additional training for operators. If appropriate, a revised testing protocol should be created to verify that the issue has been resolved and that the system now meets the intended performance threshold.

5. Operator Feedback and System Usability. In addition to performance metrics, subjective feedback from operators and engineers should be recorded through surveys or structured interviews. Topics may include:

- **Ease of use of the interface:** Operators should be asked to evaluate how intuitive and user-friendly the human-machine interface (HMI) is during system setup, monitoring, and shutdown. This includes assessing the clarity of menu navigation, accessibility of critical commands, and the responsiveness of touchscreen or manual controls. A well-designed interface improves operational efficiency, reduces the likelihood of user error, and shortens the learning curve for new personnel.
- **Clarity of system alerts and commands:** Effective alerting mechanisms are critical for maintaining situational awareness and safety during ATMA operation. Feedback should address whether warning messages, system status updates, and control prompts are easily understandable under various working conditions (e.g., low light, vibration, or noise). Operators should also comment on whether audio/visual alerts are appropriately prioritized and whether there is enough lead time to respond to system prompts.
- **Confidence in system safety and reliability:** Operators' perceptions of safety are critical to the successful adoption and sustained use of the system. Feedback should assess whether operators feel assured that the system will perform reliably, particularly during complex maneuvers or in GPS-denied environments.

It is important to gauge their trust in key features such as A-Stop and E-Stop functions, gap management, and obstacle detection. Additionally, understanding their perception of the system's reliability under different field conditions, including adverse weather or mixed traffic, is essential.

6. Final reporting and recommendations. Upon completion of the analysis, a formal test evaluation report should be developed. The report should summarize:

- Test setup and conditions
- Test case execution and repetitions
- Performance results and statistical analysis
- Summary of passes/failures
- Operator observations
- Recommendations for deployment, further testing, or system modifications

C6. CDOT test plan

- **Test Scenario 1: Emergency Stop – ATMA Internal Independent E-Stop Button**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet • Set up a barrel on the side of the path far in front of the Leader and ATMA. • Activate Leader and ATMA, drive in a straight line at **5 mph;** Activate Emergency Stop (E-Stop) inside of the ATMA when the ATMA reaches the barrel, repeat at **15 mph**; Test team will pull Leader and AIPV log data after each test Repeat each test **2 times** for statistical accuracy.
Data to Collect	● The stopping distance of ATMA, measured from the barrel to the front of the vehicle; ● The stopping time of ATMA; ● Status of Engine
Expected Result	ATMA should stop, and the stop distance and time shall be recorded, and the engine should be shut off.
Personnel Needed	Leader vehicle driver, ATMA driver, a technician to hit the E-Stop button, and a technician to record data (external).
Supporting Equipment	Traffic cones/barrels, measurement Equipment.

- **Test Scenario 2: Emergency Stop - Leader Internal Independent E-Stop Button**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet • Set up a barrel on the side of the path far in front of the Leader and ATMA. • Activate Leader and ATMA, drive in a straight line at **5 mph**; Activate Emergency Stop (E-Stop) button located in the Leader, Independent E-Stop Initiator, when the ATMA reaches the barrel, repeat at **15 mph**; Repeat **2 times** for statistical accuracy.
Data to Collect	• The stopping distance of ATMA, measured from the barrel to the front of the ATMA; • The stopping time of ATMA; • Status of Engine
Expected Result	ATMA should stop, the stop distance and time shall be recorded, and the engine should be shut off.
Personnel Needed	Leader vehicle driver, ATMA driver, a technician to hit the E-Stop button, and a technician to record data (external).
Supporting Equipment	Traffic cones/barrels, measurement Equipment.

- **Test Scenario 3: Automatic Stop - Leader Internal A-Stop Button - Both Leader Vehicles**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet • Set up a barrel on the side of the path far in front of the Leader and ATMA. • Activate Leader and ATMA, drive in a straight line at **5 mph**; Activate Automatic Stop (A-Stop) button located inside of the Leader vehicle when the ATMA reaches the barrel, repeat at **15 mph**; Repeat each test **2 times** for statistical accuracy.
Data to Collect	• The stopping distance of ATMA, measured from the barrel to the font of the ATMA; • The stopping time of ATMA.
Expected Result	ATMA should stop, and the stop distance and time shall be recorded.
Personnel Needed	Leader vehicle driver, ATMA driver, a technician to hit the E-Stop button, and a technician to record data (external).

Task	Steps for setting up the task correctly
Supporting Equipment	Traffic cones/barrels, measurement Equipment.

- **Test Scenario 4: Emergency Stop – ATMA External E-Stop Buttons**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet • Set up a barrel on the side of the path far in front of the Leader and ATMA. • Activate Leader and ATMA, drive in a straight line at 5 mph; Activate E-Stop button located on driver side of ATMA when the ATMA reaches the barrel; Repeat test 2 times for statistical accuracy. Repeat test 2 times on passenger button.
Data to Collect	• The stopping distance of ATMA, measured from the barrel to the front of the vehicle; • The stopping time of ATMA; • Status of the Engine
Expected Result	The ATMA should stop, the stop distance and time shall be recorded, and the engine should be shut off.
Personnel Needed	Leader vehicle driver, AIPV driver, and a technician to enable E-Stop buttons and record data (external).
Supporting Equipment	Traffic cones/barrels, measurement Equipment.

- **Test Scenario 5: Human Driver Stopping Times**

Task	Steps for setting up the task correctly
Operation Procedure	• Only the ATMA will be used in this test; • Set up a barrel on the side of the path far in front of the ATMA. • Manually drive the ATMA in a straight line at **5 mph**; When the ATMA reaches the barrel, manually apply full brake, repeat at **10 mph**; Repeat each test **2 times** for statistical accuracy.
Data to Collect	• The stopping distance of ATMA, measured from the barrel to the front of the vehicle; • The stopping time of ATMA;
Expected Result	The ATMA should stop, the stop distance and time shall be recorded.
Personnel Needed	ATMA driver and a technician to record data (external).

Task	Steps for setting up the task correctly
Supporting Equipment	Traffic cones/barrels, measurement Equipment.

- **Test Scenario 6: Follow Distance Change Under Hard Braking - Both Leader Vehicles**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet. • Set up a barrel on the side of the path far in front of the ATMA. • Drive Leader vehicle at a constant speed (**5mph**); Once gap has stabilized, record actual gap as reported by UI. • Once the Leader vehicle has passed the barrel, the driver will fully engage the brake; • With both vehicles stopped, record the updated actual gap, repeat at **10mph**; • Repeat each test **2 times** for statistical accuracy.
Data to Collect	• Actual gap delta • Leader and ATMA log files
Expected Result	The ATMA should stop, and the actual gap between the Leader and ATMA shall be recorded. Care should be taken to ensure that a safe GAP is used in performing this test.
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up system and export data.
Supporting Equipment	Laptop, cables to connect with ATMA, traffic cones/barrels.

- **Test Scenario 7: Driver Takeover**

Task	Steps for setting up the task correctly
Operation Procedure	• Set gap to ≥100 feet. • Activate Leader and ATMA, drive in a straight line at 10 mph; • Release the ATMA from autonomous system by switching the OCU to idle; • Human Driver takes control of the ATMA; • Repeat the test **2 times** for statistical accuracy.

Task	Steps for setting up the task correctly
Data to Collect	The time for ATMA to disengage.
Expected Result	The ATMA can quickly disengage from the system, allowing the human driver to take control.
Personnel Nee	Leader vehicle driver, ATMA driver, technician to time how quickly the human driver can take control.

Test Scenario 8: Adjusting Follow Distance - Both Leader Vehicles

Task	Steps for setting up the task correctly
Operation Procedure	• Activate the Leader and ATMA, set the Commanded Gap Distance to 75 feet, and drive in a straight line at 10mph; • Allow the ATMA gap to stabilize at 75 feet • While traveling at a steady 10mph, set the Commanded Gap Distance to **50'** and allow the Actual Gap Distance to stabilize; • Change the Commanded Gap Distance to 150' and allow the Actual Gap Distance to stabilize; • Repeat the change using the available increments from **100', 150', 200'**, **500'.** • Test team will pull Leader and ATMA log data after each test • Repeat each test **2 times** for statistical accuracy.
Data to Collect	• The speed change during the process • Stabilized follow distance accuracy
Expected Result	The ATMA can perform the Actual Gap Distance changes via the Leader User Interface (UI).
Personnel Needed	Leader vehicle driver, Leader Vehicle passenger for timing, ATMA driver, and technician to set up system and export data.
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components.

- **Test Scenario 9: Front View Collision Avoidance - Obstacle Detection**

Task	Steps for setting up the task correctly
Operation Procedure	• Activate Leader and ATMA, drive in a straight line at 5mph with the Gap set to 200 feet • Set a barrel to mark the start of the GAP far in front of the ATMA Once the rear of the Leader passes the marker barrel for the front of the Gap, a technician will place another barrel in the center of the ATMA lane to act as a stationary object.

Task	Steps for setting up the task correctly
	Test team will pull Leader and ATMA log data after each test Repeat each test 2 times for statistical accuracy.
Data to Collect	• At what distance the ATMA detects the traffic barrel • Distance between front of ATMA and traffic cone after ATMA stops
Expected Result	ATMA detects the traffic barrel and executes an A-Stop.
Personnel Needed	Leader vehicle driver, ATMA driver, and technician moving the barrel/recording data.
Supporting Equipment	Laptop, cables to connect with vehicle, traffic cones/barrels, measuring equipment.

- **Test Scenario 10: Lane Accuracy, Straight Line**

Task	Steps for setting up the task correctly
Operation Procedure	• Set up a cone lane far in front of the ATMA with a width of 144 inches • Activate the Leader and ATMA and drive in a straight line toward the cone lane at 10mph • Allow both vehicles to pass through the cone lane, repeat with a 132 inches cone lane • Test team will pull Leader and ATMA log data after each width • Repeat each test 2 times for statistical accuracy.
Data to Collect	Number of cones knocked over for each lane width
Expected Result	The ATMA can operate successfully through the cone lanes without knocking over any cones
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lanes and export data.
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components, traffic cones/barrels.

- **Test Scenario 11: Lane Accuracy, Turning**

Task	Steps for setting up the task correctly
Operation Procedure	• Set up a left/right turn cone lane with a 65 ft radius with cones spaced at an interval of 144 inches far in front of the ATMA • Activate Leader and ATMA and set the Commanded Gap distance to 100 ft. • Operate the ATMA system clockwise around the roundabout at a constant speed of 5 MPH to simulate a right turn, repeat counterclockwise to simulate a left turn, repeat with a 132 inches cone lane • Download ATMA log files. • Repeat each test 2 times for statistical accuracy.
Data to Collect	Number of cones knocked over for each lane width
Expected Result	The ATMA can operate successfully through the cone lanes without knocking over any cones
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lanes and export data.
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components, traffic cones/barrels.

- **Test Scenario 12: Acceleration Both Leader Vehicles**

Task	Steps for setting up the task correctly
Operation Procedure	• Activate Leader and ATMA and set the Commanded Gap distance to 100 ft, • After rollout, come to a full stop in both vehicles • Accelerate from 0 mph to 15 mph in a straight line in the Leader vehicle • Record the time it takes from the Leader's initial acceleration to the moment the ATMA stabilizes at the correct gap, collect logs from both the Leader vehicle and the ATMA • Repeat test 2 times for statistical accuracy.
Data to Collect	• Time it takes for the ATMA to stabilize at the correct gap
Expected Result	The ATMA can successfully reach the correct gap in a similar time frame as it would for a human driver
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to collect the time it takes for the ATMA to stabilize
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components.

- **Test Scenario 13: Max Speed Exceeded**

Task	Steps for setting up the task correctly
Operation Procedure	• Activate Leader and ATMA and set the Commanded Gap distance to 100 ft, • After rollout, come to a full stop in both vehicles • Accelerate from 0 mph to 30 mph in a straight line in the Leader vehicle • Record the max speed of the ATMA, collect logs from both the Leader vehicle and the ATMA • Repeat test 2 times for statistical accuracy.
Data to Collect	• Max speed at which the ATMA travels when the Leader vehicle is above our max acceptable speed of 20 mph
Expected Result	The ATMA will have a max speed of approximately 23 mph
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to collect the max speed at which the Follower is traveling
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components.

- **Test Scenario 14: Communications Loss between the Leader Vehicle and the ATMA**

Task	Steps for setting up the task correctly
Operation Procedure	• Activate Leader and ATMA and set the Commanded Gap distance to 100 ft, • Accelerate to 5 mph in a straight line in the Leader vehicle • Allow the ATMA to stabilize at the Commanded Gap • Power down the Leader vehicle while in operation • Repeat test 2 times for statistical accuracy.
Data to Collect	• Behavior of the ATMA
Expected Result	The ATMA will perform an E-Stop when it loses communication with the Leader
Personnel Needed	Leader vehicle driver and ATMA driver
Supporting Equipment	None

- **Test Scenario 15: GPS Loss - Both Leader Vehicles**

Task	Steps for setting up the task correctly
Operation Procedure	• Set up a long cone lane with a width of 144 inches, far in front of the ATMA

Task	Steps for setting up the task correctly
	• Set gap to ≥100 feet. • Activate Leader and ATMA, drive in a straight line at 5mph; • Remove the cable for GPS Signal of ATMA (primary antenna) and continue; • Test team will pull Leader and ATMA log data after each test • Repeat test **2 times** for statistical accuracy.
Data to Collect	The amount of time without GPS before the ATMA initiates an A-Stop Number of cones knocked down by the ATMA during each test
Expected Result	The ATMA maintains lane accuracy for a minimum of 45 seconds after GPS is lost The ATMA initiates and A-Stop in under 1 minute
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lane and export data.
Supporting Equipment	Laptop, cables to connect with M-PAK Components.

- **Test Scenario 16: Slalom/Lane Change**

Task	Steps for setting up the task correctly
Operation Procedure	Set up two 25-foot long, 144-inch wide cone lanes, offset by 12 feet with 100 feet between the two • Activate the Leader and ATMA with a Commanded Gap of 100 feet • Operate in a straight line at **5 mph** and enter one side of the slalom • Between the two cone lanes, change lanes in the Leader before entering the second cone lane, repeat at **10 mph** • Test team will pull Leader and AIPV log data after each test • Repeat each test **2 times** for statistical accuracy.
Data to Collect	Number of cones knocked down by the ATMA during each test
Expected Result	The ATMA can operate successfully through the cone lanes without knocking over any cones
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lanes and export data.
Supporting Equipment	Laptop, cables to connect with M-PAK Components, traffic cones/barrels.

- **Test Scenario 17: Obstacle Detection in Corner**

Task	Steps for setting up the task correctly
Operation Procedure	• Set up a left/right turn cone lane with a 65 ft. radius with cones spaced at an interval of 144 inches far in front of the ATMA • Activate Leader and ATMA and set the Commanded Gap distance to 100 ft. • Operate the ATMA system **clockwise** around the roundabout at a constant speed of 5 MPH to simulate a right turn • After the Leader vehicle passes the middle of the turn, place a barrel in the center of the lane, repeat **counterclockwise** to simulate a left turn • Repeat test **2 times** for statistical accuracy.
Data to Collect	Number of cones knocked down during Obstacle Detection and whether or not the ATMA stops
Expected Result	The ATMA can successfully A-Stop due to the barrel placed in the cone lane without knocking over any cones
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lanes and export data.
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components, traffic cones/barrels.

- **Test Scenario 17: Obstacle Detection in Corner**

Task	Steps for setting up the task correctly
Operation Procedure	• Set up a left/right turn cone lane with a 65 ft. radius with cones spaced at an interval of 144 inches far in front of the ATMA • Activate Leader and ATMA and set the Commanded Gap distance to 100 ft. • Operate the ATMA system **clockwise** around the roundabout at a constant speed of 5 MPH to simulate a right turn • After the Leader vehicle passes the middle of the turn, place a barrel in the center of the lane, repeat **counterclockwise** to simulate a left turn • Repeat test **2 times** for statistical accuracy.
Data to Collect	Number of cones knocked down during Obstacle Detection and whether or not the ATMA stops
Expected Result	The ATMA can successfully A-Stop due to the barrel placed in the cone lane without knocking over any cones
Personnel Needed	Leader vehicle driver, ATMA driver, and technician to set up cone lanes and export data.

Task	Steps for setting up the task correctly
Supporting Equipment	Laptop and Ethernet cable to connect with M-PAK® components, traffic cones/barrels.

Appendix D

D1. Deployment

Following successful procurement and testing of the ATMA system, the next phase is deployment into live operational settings. This section outlines the key activities to be carried out after the vehicle has been procured and validated through structured testing procedures. These activities include training of operational staff, integration of ATMA into regular maintenance workflows, establishing ongoing maintenance and support protocols, and conducting post-deployment evaluations. The goal is to ensure a smooth transition from testing to full-scale use while maintaining safety, efficiency, and compliance with agency goals.

D2. Training

Prior to full-scale deployment, all operators and relevant staff must undergo thorough training to ensure a clear understanding of the system's functionality, safety protocols, and operational procedures. This training is typically delivered by the vendor through in-person, on-site sessions that combine classroom instruction with hands-on demonstrations. To verify training effectiveness, vendors may also conduct exams or quizzes to assess participants' comprehension and preparedness for real-world use.

The figure below illustrates the core components of the training program, followed by a detailed explanation of each element:

Figure 10: ATMA Training Components

ATMA Core training components:

Component Familiarization Operators should first become familiar with the hardware and systems integrated into both the leader and follower vehicles. The table below summarizes the primary components and their associated functions:

- **Leader Vehicle System Control Unit (SCU)** – Provides central control and communication for ATMA operations
- **Battery Breaker** – Powers and protects ATMA systems (installed on both vehicles)
- **Data & Redundant Radios** – Enables and backs up V2V communication (installed on both vehicles)
- **Operator Control Unit (OCU)** – Controls start/stop and monitors system status (both vehicles)
- **E-Stop Initiator and Radio** – Emergency stop system accessible by operator (both vehicles)
- **I/O Computer and GYRO** – Facilitates obstacle detection and GPS-denied navigation (both vehicles)
- **User Interface (UI)** – Graphical interface for operation management (leader vehicle)
- **Follower Vehicle SCU** – Controls autonomous functions of the follower vehicle
- **GPS Receiver** – Provides real-time positioning data (follower vehicle)
- **External E-Stop Buttons** – Enables ground personnel to trigger emergency stop (follower vehicle)
- **Obstacle Detection Sensors (Radar, LiDAR, Ultrasonic)** – Detect and respond to obstacles (follower vehicle)
- **Actuator Assembly and Steering Actuator** – Controls braking, throttle, and steering (follower vehicle)

Key Operational Functionalities

- **Maintaining antenna functionality** – Ensures proper GPS and V2V communication through correct antenna placement and connection checks.
- **GPS navigation (primary function)** – Uses e-crumbs from the leader vehicle to guide the follower vehicle.
- **GPS-denied navigation** – Uses Inertial Measurement Unit (IMU), Gyroscope (GYRO), and Inertial Navigation System (INS) to maintain path during temporary signal loss. Triggers A-Stop if GPS loss exceeds 45 seconds.
- **Follower vehicle rollout** – Ensures the follower vehicle transitions smoothly into autonomous mode which is critical for system calibration.

- **Gap and speed control** – Maintains user-defined distance (typically 25–200 feet) behind the leader using real-time speed and position data.
- **Vehicle alignment** – Requires physical alignment of the follower vehicle's wheels and centerline with the leader vehicle.
- **Navigating corners** – Emphasizes reduced speed and staggered acceleration to allow the follower to turn safely.

General Safety Guidance

- **ATMA safety information** – Emphasize the critical importance of not altering system components, maintaining safe operating distances, and refraining from walking between vehicles while the system is active.
- **Operating procedures -** Operators must be thoroughly trained on standardized operating procedures to ensure safe and effective system use. These procedures include:
    - **Hazards and precautions** – Identification and mitigation of potential risks such as electrical hazards, fluid exposure, and failures of safety controls.
    - **Pre-start inspection** – Systematic verification of all ATMA components to confirm operational readiness.
    - **Transition to/from work zones** – Execution of approved protocols for the safe movement of the vehicle into and out of active work zones.
    - **Emergency shutdown** – Recognition of unsafe conditions and the correct initiation of emergency stop protocols.
    - **Unmanned operation procedures** – Proper initialization of the user interface, transitioning between manual and automated modes, and safely powering down the ATMA system.

D3. On-Road operations integration

Integrating an ATMA system into active roadway operations requires thoughtful planning, clear procedures, and strict compliance with safety protocols. Agencies usually establish both the operational scope and detailed step-by-step processes to ensure the system is deployed safely and effectively in live traffic settings.

D3.1 Scope of use

The ATMA vehicle may be used in both autonomous and non-autonomous modes. In non-autonomous mode, it functions as a standard truck-mounted attenuator and follows established operating procedures for traffic control. In autonomous mode, the ATMA system must remain within clearly defined parameters to ensure compliance with agency policy and legal statutes. These parameters typically include:

- Use on linear, rural arterial or collector highways with low traffic signal density
- Operation in work zones with minimal overhead obstructions or GPS interference
- Speeds typically under 10 mph
- Average daily traffic volumes generally below 2,500
- Clear visual contact between the lead and follower vehicles
- Presence of a trained safety driver in the lead vehicle capable of emergency intervention

Autonomous operations must be monitored by a designated safety observer who maintains uninterrupted visual oversight of the ATMA at all times. This individual, who is appropriately trained, licensed, and formally certified, functions as the primary operator while the vehicle operates in autonomous mode. The safety observer is responsible for remaining vigilant to identify potential hazards or obstructions, initiating emergency stop procedures as needed, and reactivating autonomous mode only after confirming that all unsafe conditions have been appropriately addressed.

Autonomous operations should be restricted to authorized maintenance activities and clearly defined operational scenarios, such as mobile striping or other approved mobile work zone functions. All use cases must adhere to established agency policies and safety protocols to ensure the technology is applied appropriately and responsibly. Prior to deployment, each ATMA operation must be reviewed and formally approved by regional transportation engineers, district safety officers, or other designated agency officials. This field-level approval process is essential to confirm the suitability of the operational context for autonomous deployment, ensure that all associated risks are effectively mitigated, and verify that all involved personnel are adequately informed and prepared to support safe execution.

D3.2 Operational Procedure

To promote safety, consistency, and accountability across various use cases, agencies may implement a standardized operational workflow for ATMA deployment. The process typically includes the following key steps:

Step 1: Conduct a Job Hazard Analysis (JHA). Before initiating any autonomous operation, conduct a formal JHA to assess site-specific conditions such as traffic volume, roadway geometry, signal presence, and potential GPS obstructions. The goal is to determine whether the planned work environment supports safe ATMA deployment under established operational constraints.

Step 2: Obtain JHA approval. Submit the completed JHA for review and approval by the appropriate regional or statewide traffic operations leadership. This ensures that all identified risks have been addressed and that the operation aligns with agency safety standards and regulatory requirements.

Step 3: Complete pre-trip inspection. Prior to deployment, operators must carry out a detailed system inspection using vendor-provided checklists. This includes checking system diagnostics, verifying GPS and V2V communications, testing actuators and sensors, and confirming software readiness. Autonomous components are activated and placed in idle mode for transit.

Step 4: Transport ATMA to work zone (Manual Mode). Move the ATMA vehicle to the work site in manual or non-autonomous mode. This ensures that operators retain full control during transit and are able to react to any unexpected roadway or traffic conditions.

Step 5: Engage autonomous mode at site. Upon arrival at the job location, transition the ATMA into autonomous mode following standard operating procedures. This transition is typically supervised by a safety observer who ensures that the system is ready for live operation and that environmental conditions remain suitable.

Step 6: Execute maintenance tasks. Complete the assigned roadway maintenance activity—such as mobile striping, cone deployment, or sweeping—while the vehicle operates autonomously. During the operation, the safety observer maintains constant visual oversight of the ATMA and remains ready to intervene if needed.

Step 7: Post trip inspection. Once the task is completed, transport the ATMA vehicle back to the maintenance yard in manual mode. Conduct a post-trip inspection to evaluate the system's performance, note any anomalies, and document findings in the operation log. This step ensures operational readiness for future deployments and facilitates troubleshooting if issues are observed.

D3.3 Emergency Stop and Incident Response Protocols

Ensuring safe operation of the ATMA system in live work zones requires robust emergency stop procedures and clearly defined incident response protocols. These protocols not only safeguard the lives of roadway workers and the traveling public, but also help maintain agency accountability and public trust in automated vehicle technologies.

Emergency Stop Conditions

All autonomous operations must be supported by clearly established emergency stop (E-Stop) procedures that are communicated to every member of the work zone team. An E-Stop allows for the immediate and complete shutdown of the follower vehicle in the event of a safety-critical situation. Any trained and authorized personnel—whether operators, safety observers, or field workers—should be empowered to initiate an emergency stop if they observe hazardous conditions, such as system malfunctions, unexpected obstacles, loss of visual contact, or erratic vehicle behavior.

Emergency stops can be triggered through multiple mechanisms: via the Operator Control Unit (OCU), the in-cab E-Stop control, or external E-Stop buttons located around the follower vehicle. In all cases, activation of the E-Stop results in the follower vehicle braking to a full stop, shutting down its engine, and disengaging the autonomous control system. If the underlying issue that triggered the E-Stop cannot be promptly diagnosed and resolved, the ATMA must revert to manual mode and continue operations under human control until further evaluation is completed.

Incident response protocols

In the event of a crash, equipment failure, or any other significant incident involving the ATMA vehicle—whether operating in autonomous or manual mode—agencies must follow a formal incident response protocol to protect personnel, preserve evidence, and meet regulatory reporting requirements. While specific actions may vary, standard response measures typically include the following, among others:

- **Immediately halt operations** and transition all ATMA vehicles to a safe and stationary condition.
- **Notify emergency services** (e.g., police, fire, EMS) as appropriate, especially in cases of injury, traffic disruption, or vehicle damage.
- **Secure the scene** to prevent further hazards and establish a safe perimeter using cones, warning signs, or flaggers to redirect traffic as needed.

- **Initiate internal reporting procedures**, including documentation of the incident, witness statements, photographs, and initial system diagnostic data.
- **Inform agency leadership**— including the director of maintenance, risk management personnel, and fleet managers, of the incident and provide regular updates.
- **Do not move the ATMA vehicle** unless authorized by law enforcement or agency safety officials, particularly if a crash investigation is underway.
- **Suspend all autonomous operations** until the root cause of the incident is reviewed and corrective actions are taken. A formal safety review must be completed and documented, and written approval from agency leadership is required before resuming autonomous operations.

D4. Driver operation in varying roadway conditions and traffic

To safely and effectively integrate ATMA into real-world roadway operations, agencies must prepare both their staff and the road environment for the specific demands of the leader-follower vehicle system. Unlike traditional driving, the ATMA system requires the leader vehicle driver to manage not just their own truck's movement but also the behavior and positioning of the autonomous follower vehicle. For example, when approaching intersections or changing lanes, the leader driver must ensure there is enough space and time for both vehicles to complete the maneuver together. The leader should avoid any actions that the follower vehicle cannot safely replicate.

Additionally, the following distance between vehicles in an ATMA convoy is different from standard driving, which is based on human reaction time. The autonomous follower responds instantly to control commands, removing human delay but requiring consideration of system precision and response behavior. Safe operations must account for the system's braking dynamics, accuracy, and protective Roll Ahead Distance (RAD) standards.

Successful deployment depends on planning for two key scenarios:

1. The minimum safe following distance between the leader and follower vehicles.
2. The minimum gap needed to safely execute a coordinated lane change.

Minimum Car-Following Distance Requirement

For the leader vehicle, maintaining a safe following distance is especially important in congested areas or when approaching intersections. According to Newell's simplified car-following model, the minimum safe distance includes: 1) the distance traveled during the driver's reaction time before braking begins, and 2) the distance covered while braking. For the leader truck, this minimum distance increases from about 20 feet at 5 mph to 75 feet at 15 mph. To ensure safety across different driving conditions, a default minimum following distance of 75 feet is recommended.

For the follower vehicle, which operates autonomously, there is no human reaction delay; braking begins immediately once triggered. Therefore, the follower's minimum required distance is primarily determined by its stopping distance and the system's margin of error in maintaining the commanded gap. Additionally, because the follower vehicle serves as a protective shadow truck, the roll-ahead distance (RAD) is a key safety factor. Based on AASHTO guidelines:

- For speed limits < 45 mph: RAD = 100 ft.
- For 45–55 mph: RAD = 150 ft.
- For > 55 mph: RAD = 172 ft.

The effective car-following distance should be set as the greater of the calculated stopping distance plus system error or the RAD value. For most urban and work zone deployments, a minimum of 100 feet is generally acceptable.

Critical lane-changing gap requirement

Lane changes can be particularly challenging for ATMA systems because both the leader and follower trucks must complete the maneuver together. For instance, when moving from lane 2 to lane 1, the maneuver must be precisely coordinated. To ensure a safe lane change, three key gaps need to be assessed:

- Lead Gap: The distance between the leader truck and the next vehicle ahead in the target lane.
- System Gap: The total length of the leader truck, the required following distance, and the follower truck.
- Lag Gap: The distance from the back of the follower truck to the nearest vehicle behind in the target lane.

All three gaps must be sufficient to allow both vehicles to change lanes safely and smoothly.

Simulation results (Qing et al. 2022) show that in freeway conditions with a speed of 70 mph and a 100-foot gap between the ATMA vehicles, a safe lane change requires a total gap of 886 to 940 feet, which equals about 25 to 47 seconds of time headway. If the internal gap between vehicles is increased to 200 feet, the required space grows to 914–968 feet, with a headway of 26–51 seconds.

Even in low-speed work zones, such as at 10 mph, the system still needs large time headways of 30–32 seconds and gap distances between 912–939 feet. These distances are much greater than what passenger vehicles need for lane changes, highlighting the importance of using additional traffic control methods like cones or flaggers to help the ATMA convoy change lanes safely without disruption.

D5. Program Marketing

Communicating the value of ATMA systems to internal and external stakeholders is critical for continued investment and broad adoption. Many DOTs leveraged multi-channel marketing efforts to inform agency leadership, field crews, partner organizations, and the public.

Efforts included:

- Hosting field demonstrations to showcase ATMA capabilities in action, often in collaboration with the vendor and local universities.
- Producing videos and brochures that describe ATMA's safety benefits and cost-saving potential.
- Conducting briefings with executive leadership and state legislators to secure long-term funding.
- Engaging with public safety agencies and the media to build public trust and raise awareness of work zone safety innovation.
- Participating in conferences and workshops to exchange best practices and deployment strategies with peer agencies.

States like Colorado and Minnesota have used workshops, web-based toolkits, and cross-agency newsletters to educate staff at all levels about ATMA integration.