Automated Truck Mounted Attenuator (ATMA)

Integration Plan

Prepared by
Virginia Tech Transportation Institute

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Revision History

Revision	Date	Comments
1.0	August 31, 2020	First Draft

Table of Contents

Introduction

The Virginia Tech Transportation Institute (VTTI) is leading a consortium consisting of DBi Services, Transurban, and the Virginia Transportation Research Council (VTRC) to design, build, and demonstrate an automated truck-mounted attenuator (ATMA) vehicle. The consortium partners have a vested interest in improving safety for the drivers of truck-mounted attenuators (TMAs). The ATMA will provide an opportunity to remove the driver from one of the most vulnerable positions within dynamic and short-duration work zones. However, the ATMA represents a relatively new technology, and current Virginia Work Area Protection Manual (WAPM) guidelines (revision 2) do not account for the use of an ATMA. Work crews will need to be aware of the technology and trained on any impacts it will have on their usual mode of operations. To fully realize the benefits of the ATMA, plans must be made to integrate it into operations at a reasonable pace. Also, current WAPM guidelines for dynamic and short-duration temporary traffic control (TTC) configurations need to be assessed to determine what role the ATMA will play and if exceptions may be generated for the addition or use of the ATMA.

This Integration Plan covers the following:

- **Testing Phases.** Recommendations for a progression of testing phases, including the nature of testing to be conducted, goals to be accomplished, criteria for successful completion, recommended facilities, and personnel and staffing recommendations.
- **Test Scenarios and Performance Metrics**. Performance measurement criteria for success or failure of the system and a plan to collect and analyze the data.
- **Training overview**. Overview of recommended training for management-level stakeholders, ATMA operators, and operational work crew members.

Testing Phases

The following sections describe VTTI's recommendations for the progression of testing the ATMA System in two testing phases: Phase 1: Controlled Environment and Phase 2: Public Roads, both of which would be completed during future follow-on phases of the project. The discussion for each phase below describes potential procedures, protocols, goals to be accomplished, and criteria for success.

Phase 1: Controlled Environment

The safety and compliance of the ATMA System shall first be evaluated on the Virginia Smart Roads, which is a controlled environment operated by VTTI at their facility in Blacksburg, Virginia. Thus, if the system were to fail, it would do so in a safe, controlled area.

This Test Scenarios and Performance Metricssection outlines the scenarios to be tested along with detailed procedures and anticipated results.

During Phase 1 of testing, the ATMA System will be tested within the limits of the operational domain design (ODD) identified. The ODD supported by the ATMA System in Phase 1 includes operational speeds between 10 and 12 miles per hour and following distance (i.e., headway) between 100 and 150 feet (the system supports a minimum of 25 feet and a maximum of 400 feet).

Personnel requirements during this testing phase include:

- One human driver in the lead vehicle (LV);
- One Control Operator in the LV, responsible for ATMA system operation
- One fallback in-vehicle test driver (FITD) or Safety Driver (SD) in the ATMA tasked with monitoring the operation and disengagements of the FV

Additionally, a safety analysis should be included when conducting any testing in a controlled environment. The successful completion of this safety analysis would allow for the transition from controlled environment testing to public road testing. This safety analysis should include, but is not limited to, the following:

- Completion of performance testing using the test scenarios detailed Test Scenarios and Performance Metrics section of this document.
- Testing engineering controls, environmental controls, redundancy object detection, and emergency stopping capabilities.

Phase 2: Public Roads

This phase would focus on a safety case regarding the selection, training, and testing protocols of FITDs (or SDs) of the ATMA for testing on public roads. This document was created based on the SAE AVSC Best Practice for In-Vehicle Fallback Test Driver Selection, Training, and Oversight Procedures for Automated Vehicles Under Test. While this best practice is not a mandatory standard or legal regulation, VTTI aims to document due diligence in considering safety and reducing the risk of public road testing.

Safety Case and Checklist for FITDs

Completed checklist items shall be indicated as completed with the initials of the responsible person in front of that item. Where necessary and indicated, a description of actions may need to be documented.

Fallback Driver Criteria

FITDs must have a valid driver's license that has been owned and legally maintained for at least 3 years. FITDs shall not have any severe moving violations on their driving record within the last 3 years. Each safety driver must initial and acknowledge this is true.

- ☐ FITDs shall complete and pass all VTTI Level 1 Safety Training and associated written tests (Smart Road Training, Basic Safety Principles, and Vehicle Operator).

- ☐ FITDs shall complete and pass VTTI's Basic Confederate Driver Training and practical evaluation.

- ☐ FITDs shall complete VTTI's Alternate Controls Training and practical evaluation. This evaluation shall consist of an operating mode that simulates the safety driver's primary task of monitoring an automated system and responding by taking over control.
  - *Description: Used an alternate control vehicle to simulate a vehicle that was under automation. The safety driver was evaluated on the ability to respond to an unexpected braking maneuver of a LV and take over manual control.*

- ☐ FITDs shall review the Phase 1 Smart Road-Testing safety assessment presentation so they are informed of proposed operations, hazards, and control methods for reducing risk.
  - *Description: The safety presentation was reviewed with safety drivers during the Alternate Control classroom training.*

- ☐ FITDs shall be knowledgeable about the automation technology used, automated driving system hardware and software, safety protocols, interfaces utilized, and communication skills utilized during testing such as:
  - Information on how automated technology works, sensors used, limitations of hardware/software/automation, etc.
  - How to conduct pre-trip inspection/testing, in-trip tasks, and post-trip debriefing as needed
  - How to enable/disable automation, how to assume control, how to know the system is engaged/disengaged, automated system typical/atypical behavior, how to recognize when there is a problem
  - Key items/events that need to be notated after testing, how to communicate with other personnel, how to communicate incidents or unexpected events

- *Description: The safety driver needs to be educated on the system operation, the responsibilities specific to the test, and how to interact with the system.*

☐ FITDs shall complete testing and gain experience using the system in a controlled environment (Smart Road) before public road testing. This testing and experience should include elements of driving and takeover specific to the targeted ODD of the automated system and expected maneuvers or required tasks (e.g., emergency stops, e-stop use, expected acceleration and deceleration profiles, expected steering profiles, transitions into and out of automation, the rationale for human takeover, responding to HMI prompts/changes, etc.)

- *Description: The safety drivers practice in a controlled environment before moving to public roadways. This needs to include scenarios that will be similar to those completed on the public roads and include aspects of intervention to maintain safety.*

Testing Protocols

The following are written protocols for safety drivers to follow during pre-trip, the trip, and post-trip. The principal investigator for the project needs to initial the following sections.

☐ ____ A **pre-trip safety inspection** of the ATMA must be completed and documented before each testing period. The checklist is available digitally via the QR code that is located in the driver's side door jam. The inspection must be completed before each testing period on the Smart Roads or on public roads. This pre-use inspection process must be part of the overall pre-trip protocol.

☐ ___ A written **pre-trip protocol** must be documented. This pre-trip protocol must be completed before each testing period (e.g., operation on public roads). The pre-trip protocol must be available to safety drivers and may include but is not limited to:

- Team Preparation Items
    - Documentation that system software is updated as necessary
    - Software/automated system testing is completed and passes testing checks
    - Test vehicle documentation available
    - Driver procedures available
    - Any advisories noted by all FITD (e.g., road construction, route obstructions, etc.)
    - Operational readiness check of all crew members
- Automated System Limitation Items

    - All limitations of an automated system are known
    - Any recent changes/updates to software and hardware are communicated to and understood by the team prior to operation
- Vehicle Safety Items
    - License, registration, and proof of insurance is available
    - Emergency protocols are available and understood
    - Emergency contact information is available
    - Vehicle conditions are satisfactory (safety inspection via QR code)
    - All sensors conditions are satisfactory
- Pre-Trip Briefing Items
    - Updates since last use are communicated to and understood by all
    - Test plan is understood by all
    - Any conditions that might affect operation have been assessed (e.g., weather, route, etc.)
    - The incident response plan is understood by all

☐ ___ A written **in-trip protocol** shall be established. The protocol may include but is not limited to:

- Maximum time of continuous operation for a FITD with an established work/rest schedule (e.g., 15 minutes rest for every 2 hours of continuous driving)
- Limitations on distractions, noise, use of electronic devices, secondary tasks, etc.
- Defined work tasks and responsibilities are delineated if more than one person is in a vehicle
- Established rules and regulations for personnel in the vehicle
- FITD monitoring (real-time or post hoc) if determined necessary

☐ ___ A written **post-trip protocol** shall be established to verbally/written/digitally report the following after testing is complete (needs to include anything that happened or that needs to happen prior to next testing session):

- Testing outcomes
- Automated driving system issues for investigation or development
- Behaviors and anomalies noted
- Environmental conditions notable for future testing
- Experienced events and incidents
- Unplanned manual interventions

☐ ___ A written **incident response protocol** shall be documented including but not limited to:

- Procedure to report to local authorities or law enforcement
- How to interact with police and first responders
- Whom to contact within VTTI
- Procedure specific to the vehicle (e.g., hazards, power source, fluid spill, fire hazards, etc.)

Test Scenarios and Performance Metrics

A test plan was created to evaluate and validate different components of the ATMA. These scenarios were based on current methods of evaluation for automated driver assistance systems.

Based on research on current system evaluation, 25 scenarios were created for the ATMA. Each scenario evaluates different potential failure areas. There are six high-level testing groups: emergency stop, environmental factors, HMI evaluation, functional components, system reaction, and system and component failure. Each scenario includes the main objective, procedure, what data to collect and how, the expected result, and the personnel and supporting equipment needed. Scenarios are listed in no particular order. The following sections outline each scenario.

Testing Scenarios Overview:

- Emergency Stop
  - Hard Stop – Tablet
  - Hard Stop – Wireless Button
  - Hard Stop – External Mushroom Button
  - Soft Stop – LV Tablet
  - Soft Stop – ATMA Tablet
  - Emergency Stop – Internal ATMA Mushroom Button
- Environmental Factors
  - Physical Road Conditions
  - Weather
  - Incline and Decline
  - Curve
- Functional Components
  - Braking Time Measurements
  - Stopping Distance
  - Target Speed
  - Following Distance Under Hard Braking
  - Driver Takeover
  - Lane Deviation
  - Longitudinal Tracking
- HMI Evaluation
  - HMI Lateral Change
  - HMI Longitudinal Change
  - Usability Test
- System Reaction
  - Vehicle Intrusion (Dynamic then Static)

    - Object Detection (Dynamic)
    - Object Detection (Static)
- System and Component Failure
    - GPS-Denied Areas
    - Sensor Failure (LiDAR, GPS, IMU)

Emergency Stop Scenario: Hard Stop – Tablet

Test Case Name	Hard Stop – Tablet
Objective	Test hard stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of hard stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the cones, the LV driver will then initiate the hard stop via the HMI tablet. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA applies maximum braking and keeps the current course (system engaged). Once stopped, the ATMA will be in a non-automated state.
Personnel Needed	LV driver, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Hard braking will be applied.

Emergency Stop Scenario: Hard Stop – Wireless Button

Test Case Name	Hard Stop – Wireless Button
Objective	Test hard stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of hard stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the cones, the external personnel will press the wireless e-stop button from outside both vehicles. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA applies maximum braking and keeps the current course (system engaged). Once stopped, the ATMA will be in a non-automated state.
Personnel Needed	LV driver, external personnel, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	The external personnel need to be near the ATMA to press the button.

Emergency Stop Scenario: Hard Stop – External Mushroom Button

Test Case Name	Hard Stop – External Mushroom Button
Objective	Test hard stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of hard stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. 4) Once the LV passes the cones, the external personnel need to press the mushroom button on the exterior of the ATMA. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA applies maximum braking and keeps the current course (system engaged). Once stopped, the ATMA will be in a non-automated state.
Personnel Needed	LV driver, external personnel, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	The external personnel need to be near the ATMA to press the button.

Emergency Stop Scenario: Soft Stop – LV Tablet

Test Case Name	Soft Stop – LV Tablet
Objective	Test soft stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of soft stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the cones, the LV driver will then initiate the soft stop (HOLD) via the HMI tablet. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA applies light to medium braking (unless other operating conditions force harder braking)
Personnel Needed	LV driver, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Abrupt braking will be applied.

Emergency Stop Scenario: Soft Stop – ATMA Tablet

Test Case Name	Soft Stop – ATMA Tablet
Objective	Test soft stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of soft stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the cones, the ATMA safety monitor will initiate the soft stop (HOLD) via the HMI tablet. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA applies light to medium braking (unless other operating conditions force harder braking)
Personnel Needed	LV driver, ATMA driver.
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Abrupt braking will be applied.

Emergency Stop Scenario: Internal ATMA Mushroom Button

Test Case Name	Emergency Stop – Internal ATMA Mushroom Button
Objective	Test emergency stop response and behavior when activated
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of emergency stop initiation. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the cones, the ATMA safety monitor will initiate the emergency stop via the internal mushroom button. 5) Repeat each condition three times (3 total trials).
Data to Collect	1) System reaction time 2) ATMA stopping distance 3) ATMA stopping time
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA disables power to all automated systems and returns the vehicle to factory control.
Personnel Needed	LV driver, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	The vehicle will be stopping at abrupt rates.

Environmental Factors Scenario: Curve

Test Case Name	Curve
Objective	Evaluate the precision and accuracy of the ATMA while following the LV around a curve
Testing Procedure	1) Set up traffic cones to designate specific curves for the ATMA to follow. 2) Three curves will be tested: (a) 75-degree turn with a radius of 45 feet, (b) 90-degree turn with a radius of 40 feet, and (c) 120-degree turn with a radius of 35 feet. 3) Initiate and begin the leader-follower sequence. 4) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 5) After the gap and speed have been achieved, the ATMA follows the LV around each curve. 6) Once the ATMA has completed the curve and maintained a straight path, the LV driver will apply the brakes at a constant rate. 7) Both vehicles have come to a stop. 8) Repeat each condition three times (9 total trials).
Data to Collect	1) Worst-case lane accuracy while going around curves 2) Curve accuracy across different types of curves (i.e., different curvatures)
How to Collect Data	Pull the data from the ATMA log file after each driver after each curve.
Expected Result	Ensure the ability of ATMA to maintain lane accuracy in curves. The tightest turning radius achievable by the ATMA is 10 meters (32.8 feet). Any tighter curve will be an invalid path.
Personnel Needed	LV driver, ATMA driver, and technician to set up the system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	LV and following vehicle are operating in coordination and relative proximity; unstable automation behavior when the curve becomes tighter; limitations of the ODD.

Environmental Factors Scenario: Incline and Decline

Test Case Name	Incline and Decline
Objective	Evaluate the stopping distance across different road grades
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) ATMA braking will be tested on both an incline and a decline. The Smart Road has a 6% maximum incline on the highway, and 0% include on the surface. 5) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a constant rate. 6) Both vehicles have come to a stop. 7) Repeat both conditions three times (6 total trials).
Data to Collect	1) Different distances
How to Collect Data	Measure the actual gap distance between the LV and the following ATMA.
Expected Result	Ensures the ability of ATMA to achieve stopping distance across different conditions. The system should maintain the same safe distance as the programmed following distance unless the operator is exceeding the dynamics of the vehicle.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Unstable automation behavior

Environmental Factors Scenario: Physical Road Conditions

Test Case Name	Physical Road Conditions
Objective	Evaluate the stopping distance across different physical road conditions (i.e., smooth pavement, gravel road, and dirt road)
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Three physical road conditions will be evaluated: (a) smooth pavement, (b) gravel road, and (c) dirt road. 5) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a constant rate. 6) Both vehicles have come to a stop. 7) Repeat each condition three times (9 total trials).
Data to Collect	1) Different distances
How to Collect Data	Measure the actual gap distance between the LV and the following ATMA.
Expected Result	Ensures the ability of the ATMA to achieve stopping distance across different conditions. The system should maintain the same safe distance as the programmed following distance unless the operator is exceeding the dynamics of the vehicle.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, and technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Varying stopping distances, unstable environmental conditions

Environmental Factors Scenario: Weather Conditions

Test Case Name	Weather
Objective	Evaluate the stopping distance during different weather conditions (i.e., clear day, cloudy day, and rain).
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Three weather conditions will be evaluated: (a) clear day, (b) cloudy day, and (c) rain. 5) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a constant rate. 6) Both vehicles have come to a stop. 7) Repeat each condition three times (9 total trials).
Data to Collect	1) Different distances
How to Collect Data	Measure the actual gap distance between the LV and the following ATMA.
Expected Result	Ensures the ability of ATMA to achieve stopping distance across different conditions. The system should maintain the same safe distance as the programmed following distance unless the operator is exceeding the dynamics of the vehicle.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data.
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Unstable environmental conditions

HMI Evaluation Scenario: HMI Lateral Change

Test Case Name	HMI Lateral Change
Objective	Evaluate the accuracy of the HMI when a lateral offset changes is input
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of the lateral change. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the set of traffic cones, the LV driver changes the HMI lateral offset. 5) Vehicles should continue to drive (Lateral Change is an instantaneous computation). 6) LV driver will apply the brakes at a constant rate, and both vehicles have come to a stop. 7) Repeat this test three times (3 total trials).
Data to Collect	1) Worst-case lateral offset accuracy during the lane change 2) Time for the system to adjust to the offset change
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	Ensures the ability of ATMA to maintain offset accuracy when a change is entered through the HMI
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data.
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Limitations of the ODD

HMI Evaluation Scenario: HMI Longitudinal Change

Test Case Name	HMI Longitudinal Change
Objective	Evaluate the accuracy of the HMI when longitudinal changes are input
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of change. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the set of traffic cones, the LV driver changes the following distance through the HMI. 5) Vehicles should continue to drive. 6) LV driver will apply the brakes at a constant rate, and both vehicles come to a stop. 7) Repeat this test three times (3 total trials).
Data to Collect	1) Speed change during the process 2) Stabilized following distance accuracy 3) Time for the system to adjust to the gap change
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	ATMA adjusts to the changes in the longitudinal offset
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data.
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Limitations of the ODD

HMI Evaluation Scenario: Usability Test

Test Case Name	Usability Test
Objective	Understand which controls drivers interact with to stop ATMA during different scenarios
Testing Procedure	1) This requires a user test with safety driver operators. 2) Participants will be asked to complete different tasks using the interface inside the LV cabin. 3) The order of tasks will be counterbalanced to minimize any order effects. 4) While participants are completing tasks, the number of errors and time of task completion need to be recorded by the moderator. Researchers will also gather expert observations on communication understanding, types of errors, hesitations, and confusion. 5) Participants will be asked to think aloud while completing tasks. 6) After each task, participants will be asked to complete different forms of qualitative feedback on their experience. Further discussions will probe what drives participants' responses. 7) After completing all tasks, participants will be asked to provide a rating on user experience metrics such as desirability and then discuss what led to that rating. Confusion points and expectations will be discussed to unearth potential design improvements.
Data to Collect	1) Basic user metrics 2) Errors using the system 3) Time to complete tasks 4) Qualitative metrics
How to Collect Data	Data will be collected via rating sheets, timer for the length of task time, and a notetaker.
Expected Result	Users will be able to complete tasks with relative ease of use.
Personnel Needed	Potential vehicle operator, moderator, notetaker
Supporting Equipment	Interface, timer, rating sheets, discussion guide
Safety Implication(s)	Since testing would be conducted in a controlled, static environment, results may differ when the system is in full motion.

Functional Component Scenario: Braking Time Measurements

Test Case Name	Braking Time Measurements
Objective	Evaluate the deceleration profile of the system
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a constant rate. This is to test normal braking and emergency braking. 5) Both vehicles have come to a stop. 6) Repeat this test three times (3 total trials).
Data to Collect	1) Deceleration profile
How to Collect Data	Pull the data from the ATMA log file after each braking maneuver.
Expected Result	ATMA maintains a deceleration profile of ±3 m/s_2 for general speed and brake commands. For high-brake events (e.g., e-stop), 100% brake effort is applied.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	The vehicle will be braking at different rates.

Functional Component Scenario: Stopping Distance

Test Case Name	Stopping Distance
Objective	Evaluate the stopping distance across different speeds
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) There will be three trials: stopping at a speed of (a) 10 mph, (b) 25 mph, and (c) 40 mph. 5) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a normal braking rate. 6) Both vehicles have come to a stop. 7) Repeat each condition three times (9 total trials).
Data to Collect	1) Different distances
How to Collect Data	Measure the actual gap distance between the LV and the following ATMA.
Expected Result	Ensures the ability of ATMA to achieve stopping distance under different conditions. The system should maintain the same safe distance as the programmed following distance unless the operator is exceeding the dynamics of the vehicle.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	The vehicle will be braking and stopping at different rates.

Functional Component Scenario: Target Speed

Test Case Name	Target Speed
Objective	Measure if the system has reached the target speed and the time
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Confirm that the system has achieved the set speed and following distance. 5) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a constant rate. 6) Both vehicles have come to a stop. 7) Repeat both conditions three times (6 total trials).
Data to Collect	1) Speed achieved
How to Collect Data	Confirm that the ATMA achieved the set speed and following distance.
Expected Result	Ensures the ability of ATMA to achieve and maintain speed
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Varying speeds and potentially unstable automation behavior

Functional Component Scenario: Following Distance Under Hard Braking

Test Case Name	Following Distance Under Hard Braking
Objective	Understand the ATMA's reaction if the LV were to make an abrupt stop
Testing Procedure	1) Place traffic cones on the side of the road to indicate the braking location across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the set of traffic cones, the LV driver will apply the brakes at a hard rate. 5) Both vehicles have come to a stop. 6) Repeat this test three times (3 total trials).
Data to Collect	1) System reaction time 2) Ability of system to make the adjustments
How to Collect Data	Pull the data from the ATMA log file after each braking maneuver.
Expected Result	The ATMA will decelerate at the same rate until a violation occurs. At that point (i.e., vehicle is too close), it will e-stop.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	LV and following vehicle are operating in coordination and relatively close proximity. Vehicles will be stopping at abrupt rates.

Functional Component Scenario: Driver Takeover

Test Case Name	Driver Takeover
Objective	Evaluate the system when the safety driver regains control of the ATMA
Testing Procedure	1) Place two sets of traffic cones on the side of the road: (a) to indicate the disengagement location and (b) the location of reengagement (approximately 500 feet away). 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. 4) Disengage the ATMA from autonomous mode via the interface. 5) Reengage the system to autonomous mode via the interface. 6) Once the ATMA is in autonomous mode, and both operators confirm this (via communication device), then both vehicles come to a stop. 7) Repeat this test three times (3 total trials).
Data to Collect	1) Time for ATMA to disengage
How to Collect Data	Using a timer (or if the data can be pulled from the ATMA), collect the time it takes for the system to reengage autonomous mode from disengagement.
Expected Result	ATMA will quickly disengage from the system, allowing the safety driver to take control.
Personnel Needed	LV driver, ATMA driver
Supporting Equipment	LV, ATMA, Traffic Cones, Timer, Communication Device
Safety Implication(s)	Vehicle operators – lack of vigilance/distraction during testing; safety driver awareness

Functional Component Scenario: Lane Deviation

Test Case Name	Lane Deviation
Objective	Understand the ATMA reaction if the LV were to make an abrupt change in course
Testing Procedure	1) Place one set of cones to indicate where to initiate a lane change. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. 4) When the LV reaches the traffic cones, the LV shall perform a lane change maneuver. 5) Have the LV and ATMA continue driving. 6) Both vehicles have come to a stop. 7) Repeat this test three times (3 total trials).
Data to Collect	1) System reaction time 2) Ability of system to make the adjustments
How to Collect Data	Pull the data from the ATMA log file after each lane-change maneuver.
Expected Result	ATMA detects the change and adjusts to the lane change.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Limitations of the ODD, unstable automation behavior

Functional Component Scenario: Longitudinal Tracking

Test Case Name	Longitudinal Tracking
Objective	Evaluate how the system performs over an extended time
Testing Procedure	1) Initiate and begin the leader-follower sequence. 2) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 3) Have the system run continuously for 10 minutes. 4) Have the LV and ATMA continue driving. 5) Both vehicles have come to a stop. 6) Repeat this test three times (3 total trials).
Data to Collect	The accuracy of the longitudinal tracking.
How to Collect Data	Pull the data from the ATMA log file after each trial.
Expected Result	ATMA maintains the following distance. There will be some known variation in simply running this test with the LV.
Personnel Needed	The leader vehicle driver, ATMA driver.
Supporting Equipment	LV, ATMA
Safety Implication(s)	Limitations of the ODD, unstable automation behavior

System Reaction Scenario: Vehicle Intrusion (Dynamic then Static)

Test Case Name	Vehicle Intrusion (Dynamic then Static)
Objective	Understand how the ATMA reacts when a vehicle breaches the safety zone between the ATMA and the LV. Understand ATMA system latency from when an event occurs to when the System informs the operator and safety driver.
Testing Procedure	1) Place a set of traffic cones where the intruding vehicle will breach the safety zone. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. 4) Once the LV reaches the set of cones, the intruding "vehicle" will breach the safety zone. This intruding vehicle can be a 3' x 3' x 3' box that is released from the back of the LV. The box can be dragged along on a rope that is fed out to get it close to the ATMA. 5) The intruding "vehicle" shall slowly decrease its speed by 5 mph. The length of the rope will increase. 6) The intruding "vehicle" shall slowly increase its speed by 5 mph. The rope will be decreased in length. 7) Have the intruding "vehicle" come to a complete stop. The rope can be dropped, so the object remains behind. 8) Repeat each condition three times (3 total trials).
Data to Collect	1) Distance the ATMA detects the vehicle that breached the safety zone 2) Distance between the front of ATMA and "vehicle" after ATMA stops 3) The time it takes from when the incident occurs to when the system reacts 4) Whether or not the ATMA performs differently
How to Collect Data	Once the safety zone is breached, monitor the ATMA’s behavior.
Expected Result	ATMA detects the vehicle and executes an e-stop.

Personnel Needed	LV driver, ATMA driver, intruding object operator, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones, Intruding Object
Safety Implication(s)	Since another "vehicle" (object) will be interrupting the leader-follow configuration, the potential for a hazard increases.

System Reaction Scenario: Object Detection (Static)

Test Case Name	Object Detection (Static)
Objective	Understand how the ATMA reacts when an object breaches the safety zone between the system and the LV Understand the ATMA system latency from when an event occurs to when the System informs the operator and safety driver
Testing Procedure	1) Place a set of traffic cones where the intruding object will breach the safety zone. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV reaches the set of cones, the intruding object will breach the safety zone. The object should be deployed between 98 and 131 feet in front of the ATMA. 5) The ATMA should come to a complete stop. 6) Repeat each condition three times (3 total trials).
Data to Collect	1) The distance at which the ATMA detects the object that breached the safety zone 2) Distance between the front of ATMA and "object" after ATMA stops 3) The time it takes from when the incident occurs to when the System reacts 4) Whether or not the ATMA performs differently
How to Collect Data	Once the safety zone is breached, monitor the ATMA's behavior.
Expected Result	ATMA detects the object and executes an e-stop.
Personnel Needed	LV driver, ATMA driver, object launcher, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones, Intruding Object
Safety Implication(s)	Since an object will be interrupting the leader-follow configuration, the potential for a hazard increases.

System Reaction Scenario: Object Detection (Dynamic)

Test Case Name	Object Detection (Dynamic)
Objective	Understand how the ATMA reacts when an object moves differently. Evaluate if there is a difference between the ATMA's performance if the object that breached the safety zone moves or does not.
Testing Procedure	1) Place a set of traffic cones where the intruding object will breach the safety zone. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. 4) Once the LV reaches the set of cones, the intruding object will breach the safety zone. The same box can be used from the Vehicle Intrusion Scenario. The object should be deployed between 98 and 131 feet in front of the ATMA. 5) The object should move slowly across the safety zone in front of the ATMA. 6) The ATMA should come to a complete stop. 7) Repeat each condition three times (3 total trials).
Data to Collect	1) Is there a difference between the stopping distances of the ATMA when it detects different types of objects? If so, what is that difference? 2) Measure the distance it takes for the ATMA to stop for the different types of objects.
How to Collect Data	Once the safety zone is breached, monitor the ATMA's behavior.
Expected Result	There is no timing difference between types of objects. The ATMA is expected to detect the object and execute an e-stop.
Personnel Needed	LV driver, ATMA driver, technician to set up the system and export data
Supporting Equipment	LV, ATMA, Traffic Cones, Intruding Object
Safety Implication(s)	Since an object will be interrupting the leader-follow configuration, the potential for a hazard increases.

System and Component Failure Scenario: GPS-denied Areas

Test Case Name	GPS-denied Areas
Objective	Understand how the system operates under different availabilities of GPS
Testing Procedure	1) Two sets of traffic cones will need to be placed. a) Place traffic cones on the side of the road to indicate the location of the GPS cut-out across trials. b) Place traffic cones at the point where the LV and ATMA should begin to brake to come to a stop and end the trial. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 mph. 4) Once the LV passes the first set of traffic cones, the GPS signal to the ATMA will be cut. 5) Have the LV and ATMA continue driving. Once the LV passes the second set of cones, the LV driver will apply the brakes at a constant rate. 6) Both vehicles have come to a stop. 7) Repeat this test three times (3 total trials).
Data to Collect	1) The amount of time the ATMA maintains its lateral offset accuracy 2) The amount of time the ATMA maintains its longitudinal offset accuracy
How to Collect Data	The test team will pull the log data from the ATMA after each trial.
Expected Result	The ATMA maintains lane accuracy after GPS is lost.
Personnel Needed	LV driver, LV passenger for timing, ATMA driver, technician to set up system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Limitations of the ODD, unstable automation behavior

System and Component Failure Scenario: Usability Test

Test Case Name	Sensor Failure (LiDAR, GPS, IMU)
Objective	Evaluate different ATMA sensors to understand what will happen if a system were to fail during operation
Testing Procedure	1) Place traffic cones on the side of the road to indicate the location of communication disconnection across trials. 2) Initiate and begin the leader-follower sequence. 3) LV and following ATMA shall obtain a following gap between 100 and 150 feet and a constant speed between 10 and 12 miles mph. (a) Communication links: Disconnect the communication line. (b) Hardware-level: Disconnect a piece of hardware (i.e., unplug the cable to LIDAR or IMU or GPS). (c) Steering control: Disconnect steering control. 4) Both vehicles have come to a stop. 5) Repeat each condition three times (9 total trials).
Data to Collect	1) Distance to stop from when the sensor failed 2) Time to stop from when the sensor failed
How to Collect Data	Once either communication link is disconnected, pull the data from the ATMA log file. If manual data collection is required, start a timer and end when the system comes to a stop. Manual data collection may be inconsistent across the data collector.
Expected Result	(A) Communication links: Loss of communication will force a soft-stop condition. (B) Hardware-level: VCB control boards provide heartbeats. Loss of communication here will revert the system to hardware pass-through override and a fault state. (C) Steering control: Loss of communication or response will force a stop state. The HMI will display a “No Communication” warning to the operator and safety driver.
Personnel Needed	LV driver, ATMA driver, technician to set up the system and export data
Supporting Equipment	LV, ATMA, Traffic Cones
Safety Implication(s)	Limitations of the ODD, unstable automation behavior

Training Overview

VTTI created an ATMA Training Document PowerPoint for both management and operators to review in conjunction with general TMA training. The ATMA Training Document includes supplemental information on the changes between the TMA and ATMA vehicles and should be used in parallel with regularly required TMA training. This does not eliminate the need to train operators on basic TMA operations.

The ATMA training document includes an overview of ATMA goals, benefits, and changes in technology. The test cases are explained at a high level. Detailed explanations of the internal HMI system states, location of the interfaces, functional state flow, and interface components are included. Additionally, the external communication components are explained, and videos are included to depict what will be seen in a real-world environment.

Learning Objectives for Both Training Levels

Upon completion of this training, participants should be able to understand the following functions of the ATMA:

1. ATMA Overview
    - Goals
    - Benefits
    - Technology
    - Test Cases
2. ATMA system states and transitions between states
3. Internal HMI
4. External communication components