ATMA Performance Verification Week 1 Info Packet

June 26-30

Communication Plan

Media questions: Contact Amy Ford, all media activities must be cleared by her first

Hardware Installation questions: Carl Hunter, Glen Larmore

Vehicle Systems Hardware questions: Glen Larmore

Vehicle Systems Software questions: Won Kyaw

Procedures/Scenarios questions: Joe Meyer

Facility questions: Dr. Tom Bradley, Mark Jackson

Material/Equipment needs: Rod Dudley

Other: Tyler Weldon

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Vehicle Performance Verification Schedule Overview

Week of June 26: Systems performance validation on track with striping truck as lead vehicle

Week of August 21: Systems performance validation on track with mower and sweeper as lead vehicles

ON HOLD September 19, 20: FHWA Showcase Event

Vehicle Performance Verification Week 1 Schedule

Monday, June 26: Installation of Lead Vehicle Hardware and Airfield Setup

Tuesday, June 27: System Verification Day – Braking and Safety Systems

Wednesday, June 28: System Verification Day – Following Capability Performance

Thursday, June 29: System Verification Day – Vehicle Limitations and Operational Predictability

Friday, June 30: Week 1 Debrief, System Demonstrations for CDOT and partner agency personnel

Vehicle Performance Verification Week 1 Locations

Vehicle Performance Verification Facility:

Christman Field

3985 Laporte Ave

Fort Collins, CO 80521

Vehicle Delivery & Storage Facility:

CDOT Region 4 Headquarters

10601 US34 Business Route

Greeley, CO 80634

Figure 1: Fort Collins (Vehicle Performance Verification Location) in relation to Greeley (Delivery/Storage Location) and Denver

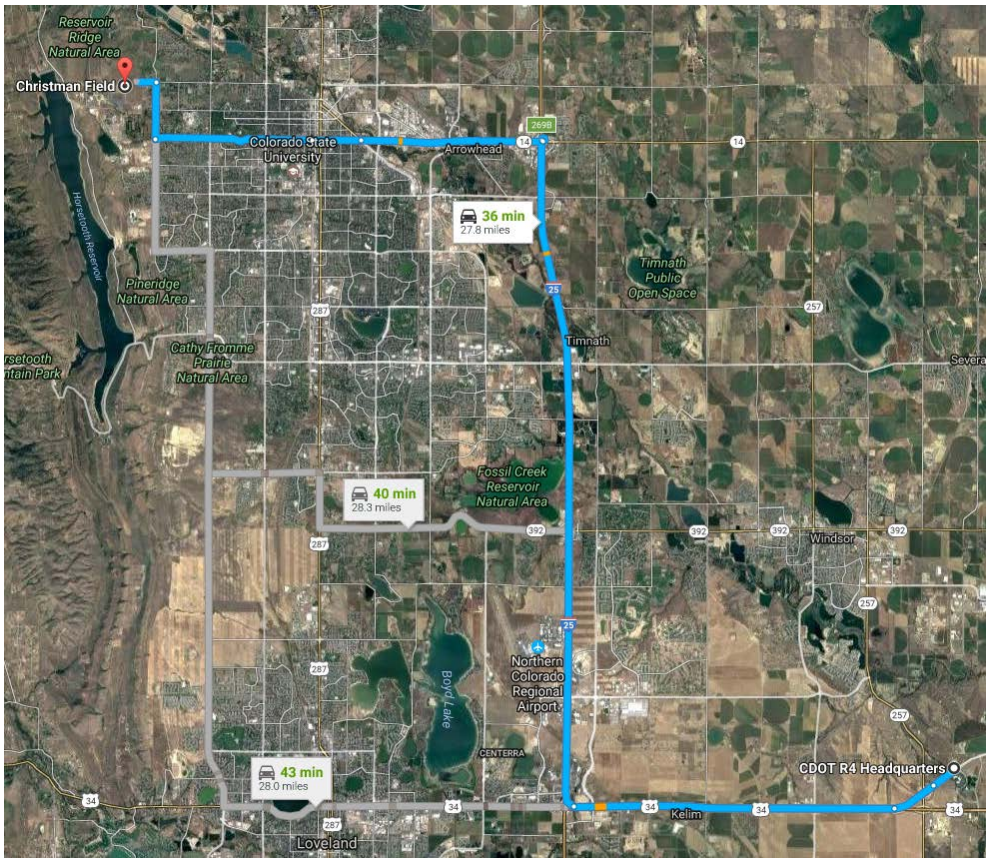


Figure 2: Vehicle Performance Verification Location in relation to vehicle storage location

Figure 3: Vehicle Performance Verification Location, Christman Field

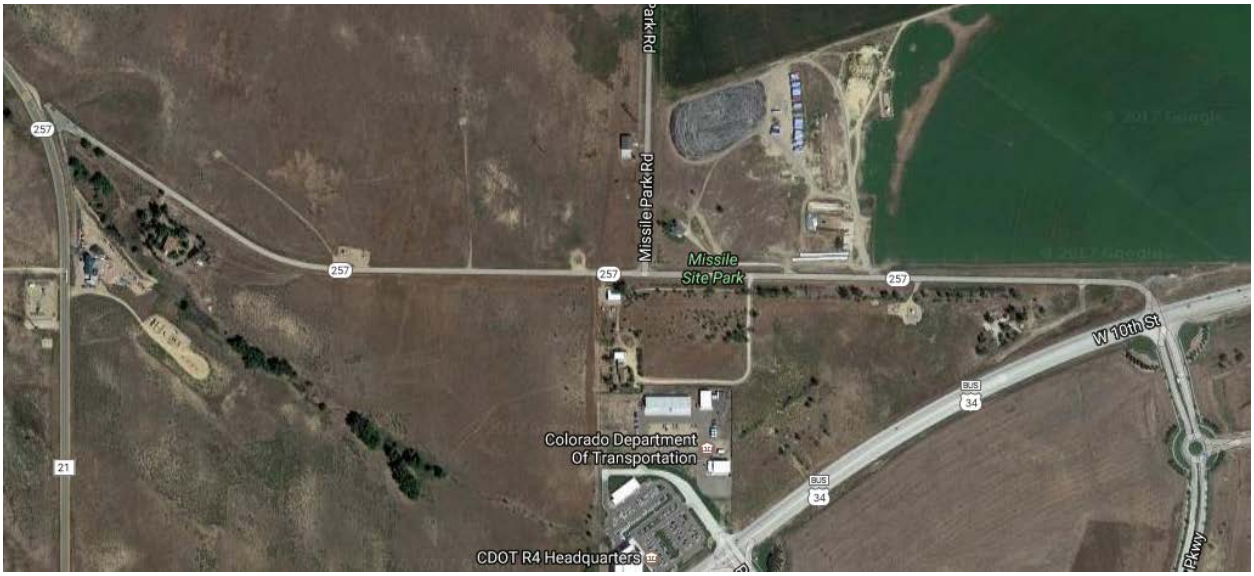


Figure 4: Spur road (CO 257) behind storage location, to use for calibration

Vehicle Performance Verification Location Setup

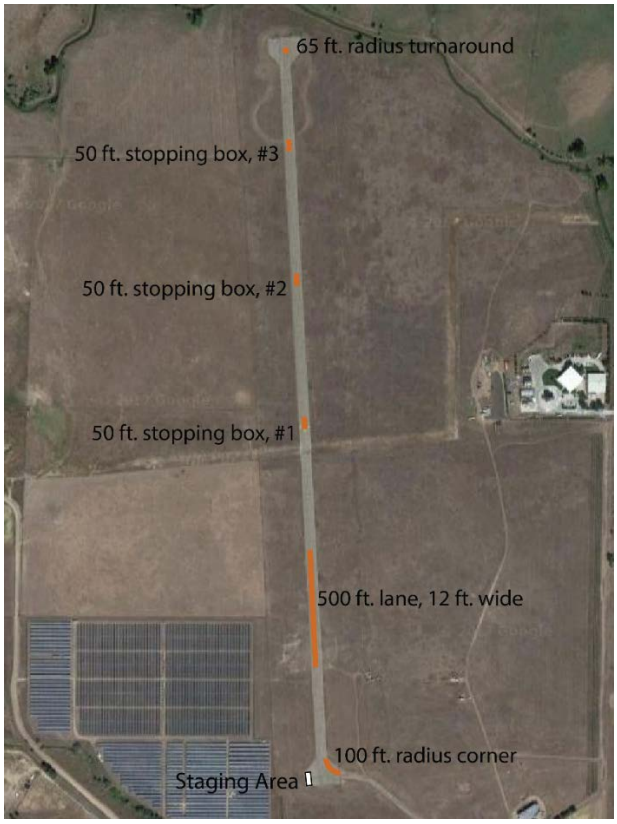


Figure 5: Vehicle Performance Verification Location Setup and Cone Areas

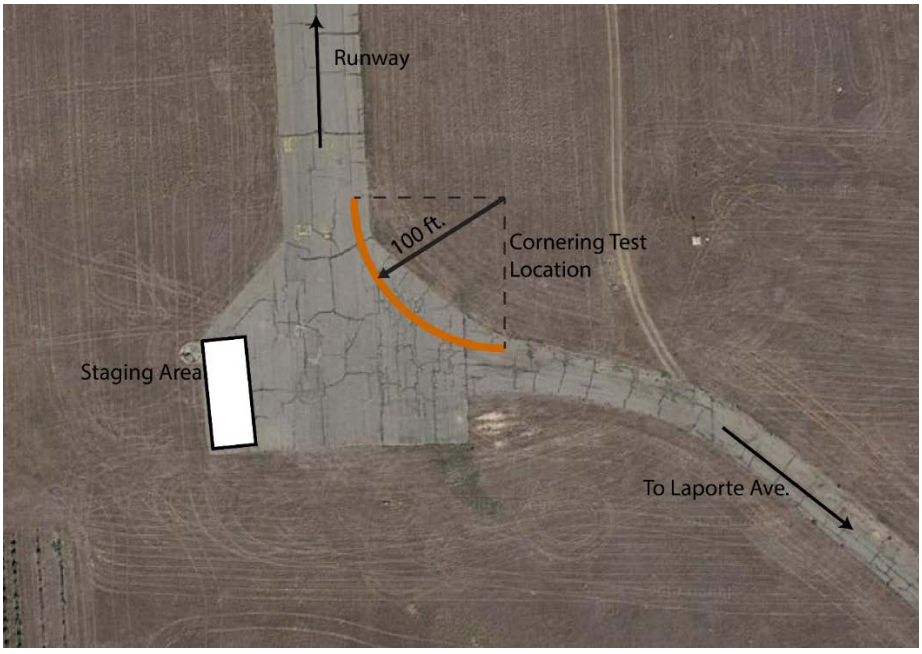
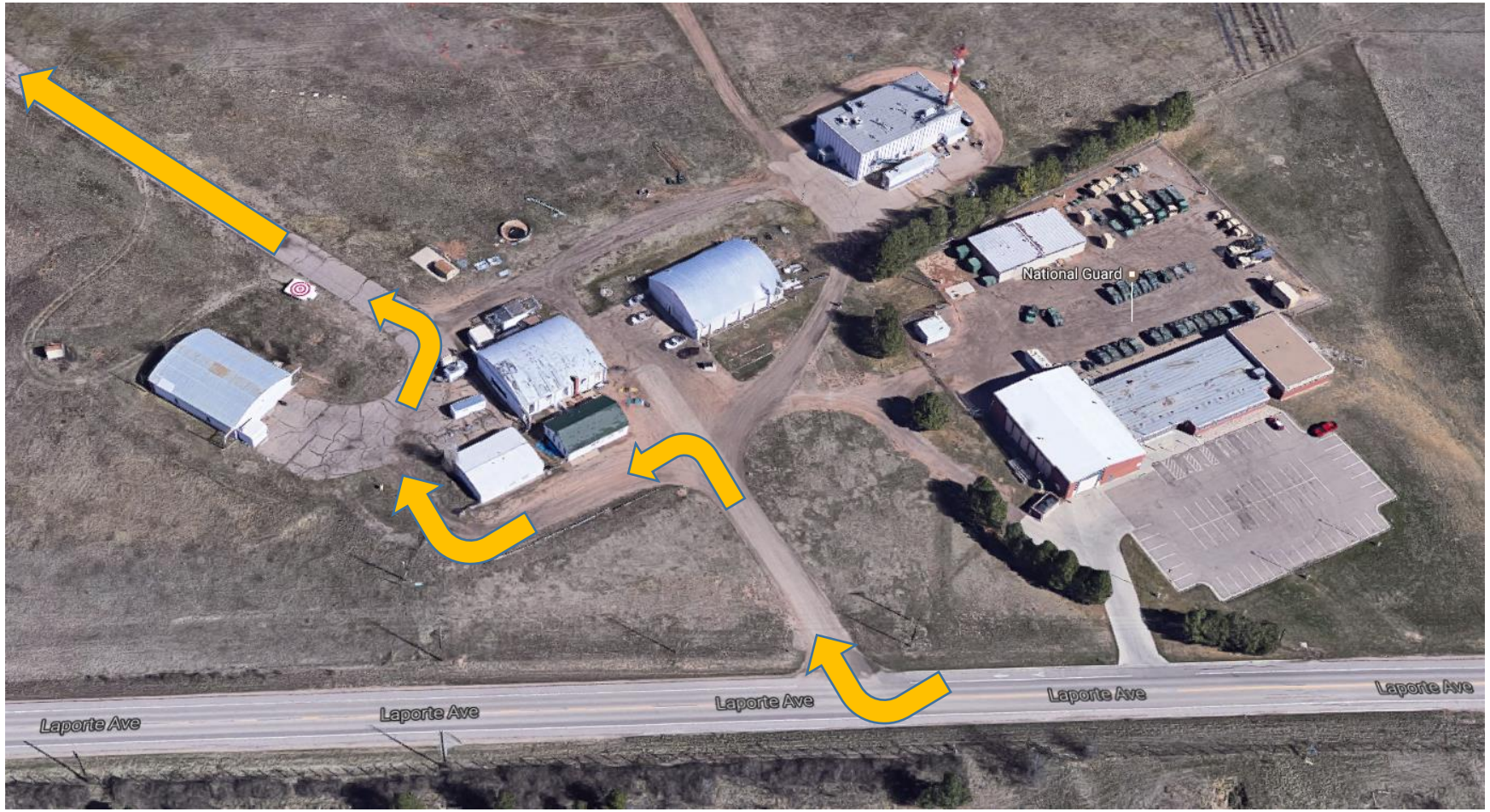


Figure 6: Closeup of Cornering Performance Verification Location

Access to: Colorado State University Christman Field
3985 Laporte Ave, Fort Collins, CO 80521



- Contact Point
  - Associate Professor of Mechanical Engineering, Dr. Thomas Bradley 970-237-1305
- In case of emergency
  - Call 911
  - Location is CSU Christman Field

Colorado State University

Turn Right from LaPorte Ave after METEC sign

Enter the field through the gate to the left of the buildings

Enter the field by driving along the path to the right of the “target” trailer

General Safety Warnings

- Beware of wildlife including deer, snakes
- We will share the facility with other users including funded research on Natural Gas leaks, do not disturb equipment or other research
- Watch your step: unmarked rocks, holes, other tripping hazards.

Restroom and Shelter at Daryl B. Simons Building CSU “Engineering Research Center” Campus

- Exit Airfield
- Right (West) on Laporte Ave
- Turn left into CSU “ERC” Campus
- Enter Simons Building through front door, turn left for mens, right for womens.

Vehicle Performance Verification Plan

Monday, June 26

Region 4 Headquarters, Greeley

8:00am **Welcome and Vehicle Performance Verification Week 1 Planning Meeting.**

Personnel: All CDOT onsite personnel, all MSI onsite engineers.

9:00am **Installation of lead vehicle hardware on striping truck.**

Personnel: All MSI onsite engineers, Shane Ridings, Rod Dudley.

12:00pm **Break for lunch.**

1:00pm **Finish install, tune system at Greeley shop.**

Personnel: All MSI onsite engineers, Shane Ridings, Rod Dudley, Larry Haas, Tyler Weldon, Joe Meyer.

Christman Field, Fort Collins

9:00am **Setup track for vehicle performance verification scenarios.**

Personnel: Joe Meyer, Tyler Weldon, Larry Haas, 2 Region 4 volunteers.

Materials: Cones, Chairs, Tables, Canopy, Tape Measure, Generator, Fan, Storage Trailer.

Tuesday, June 27

Christman Field, Fort Collins

The following scenarios are designed with the purpose of validating the safety, performance, limitations, and predictability of the operation of the follower vehicle. The predictability is especially key for CDOT, as the maintenance workers must be able to know what actions to expect from the vehicle. CDOT's scenarios will verify previous testing conducted by MSI along with their statements of the vehicle's performance. Results from most of these scenarios should be directly comparable to results produced by MSI for accurate verification of the system.

Braking and Safety Systems Performance Scenarios

Setup for all braking scenarios will include a straight section of cones, spacing of 5' for a distance of 50'. When possible, a camera on a tripod will be set up, filming this designated section from the side. This will be used to estimate the braking distances of the vehicles in addition to the speed data from the onboard sensors. All braking will be conducted within this area. Three of these will be set up along the length of the runway to allow for multiple stopping behavior verifications to be conducted without turning the vehicles around.

7:30am **Conference call briefing with offsite interests.**

Call Number: 1-877-820-7831, Code: 704136#

8:00am **Layout of week's plan. Layout of plan for day 1 scenarios. Breakfast.**

Personnel: All CDOT Region 4 striping crew, Joe, Tyler, MSI Engineers, CSU student researchers.

9:00am **Scenario 1 – Emergency Stopping (in-cab)**

Link leader and follower vehicle, drive in a straight line at 7 mph. Activate emergency stop in cab of leader truck to ensure effectiveness. Repeat at 10, 15, 20, and 25 mph. (20 and 25 mph for characterization of truck only) Repeat at all three speeds using emergency stop in cab of follower (TMA) truck.

Repeat each scenario 3 times for statistical accuracy.

MSI engineer will ride along to pull speed/position data from ATMA to determine stopping distance.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in follower to record data.

Materials: Laptop and associated cables to interface to vehicle.

10:00am **Scenario 2 – Emergency Stopping (external)**

Activate each of the external emergency stop buttons at a speed of 5 mph.

Repeat 3 times with each button.

MSI engineer will ride along to pull speed/position data from ATMA to determine stopping distance.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in follower to record data, Joe will hit e-stop buttons.

Materials: Laptop and associated cables to interface to vehicle.

11:00am **Scenario 3 – Automated System vs. Human Driver Stopping Distance Comparison**

Have human driver operate ATMA, with a passenger. Drive at constant speed (Perform at same speeds as Scenario 1. Rider will say "Stop" and start timing. Record time from spoken "Stop" to complete stop.

Repeat 3 times for accuracy.

MSI engineer will ride along to pull speed/position data to determine stopping distance with and without including the reaction time of the drive.

Compare stopping distance and time of emergency stop button activated stops to human driven stops, with and without reaction time included. Ensure that e-stop buttons perform equally or better than a human driver, reaction time included.

Personnel: ATMA driver (R4 striping), MSI engineer riding in ATMA to record data, 2nd passenger in ATMA with stop watch.

Materials: Laptop and associated cables to interface to vehicle, stopwatch.

12:00pm **Break for lunch.**

1:00pm **Scenario 4 – Follow Distance Under Hard Braking**

Drive lead vehicle in a straight line at 7, 10, 15, and 20 mph (20mph for characterization only) and brake suddenly. Have a passenger in the lead vehicle time the braking.

Use the position/speed data from the ATMA to determine braking time and distance.

Use GPS data on leader and follower to determine following distance during braking event.

Determine change in follow distance during emergency stop. Ensure a change in following distance is within safe limits.

Repeat each scenario 3 times for statistical accuracy.

Personnel: Lead vehicle driver (R4 striping), lead vehicle passenger for timing (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in follower to record data.

Materials: Laptop and associated cables to interface to vehicle, stopwatch.

2:00pm **Scenario 5 – Recoverability by Driver**

Verify seamless ability of human operator of ATMA to take over – check ease and speed of operation of override switch. Perform similar stopping scenario as in scenario 3, with human driver taking control from self-driving ATMA upon a “stop” command from passenger.

Compare stopping distance and time of human driver to human driver taking over from automated system. Ensure that stopping times and distance are within tolerance to show minimal delay in takeover of human operator.

Repeat each scenario 3 times for statistical accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA passenger for timing (R4 striping), ATMA safety rider/driver (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle, stopwatch.

3:00pm **Scenario 6 – Obstacle Detection**

Verify obstacle detection radar performance. Place a 28” or larger traffic cone in between the vehicles as they drive. Perform initially at 7 mph, increase speed upon successful validation. Ensure that the ATMA stops before hitting cone.

Have MSI engineer ride along to pull speed/distance data and compare to behavior of emergency stop buttons. Stopping distance/time should be similar to show that maximum braking is applied upon obstacle detection.

Repeat each scenario 3 times for statistical accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle, traffic cone.

4:00pm **Debrief Day 1, with conference call for offsite participants.**
Determine current progress and plan to conduct additional scenarios Wednesday, June 28 if necessary.

Call Number: 1-877-820-7831, Code: 704136#

Wednesday, June 28

Christman Field, Fort Collins

Following Capability Performance Scenarios

7:30am **Conference call briefing with offsite interests.**

Call Number: 1-877-820-7831, Code: 704136#

8:00am **Layout of plan for day 2 scenarios. Breakfast.**

Personnel: All CDOT Region 4 striping crew, Joe, Tyler, MSI Engineers, CSU student researchers.

8:30am **Scenario 7 – Follow Distance Adjusting**
Explore follow distance capabilities by having follow distance adjusted by MSI software engineer. Also characterize how follow distance is affected by speed. Drive at 7, 10, 15, and 20mph. Perform scenario in a straight line.

Record data from GPS waypoints on leader and follower to calculate follow distance.

Repeat with human driver driving ATMA. Log following distance and compare to automated system. Deviation of automated system must be comparable or lower than human driven.

Perform once at each speed, for half of the runway distance (2000') each run.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider/driver (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

9:30am **Scenario 8 – Lane Accuracy, Straight Line**

Set up a "lane" using cones, 12' wide, 500' long, cone spacing of 10'. 100 cones required. Verify the ability of the ATMA to follow behind the leader truck between the cones without straying left or right out of the "lane". Repeat at three different speeds to ensure higher speeds do not diminish lane accuracy. Repeat with 10' lane. Reduce lane until it is barely wider than the vehicles and repeat.

Mount GoPro cameras on leader vehicle looking back, and on follower vehicle looking forward, for collection of qualitative data of variation in follower's path.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping).

Materials: Cones placed in a "lane", GoPros and mounts.

10:30am **Scenario 9 – Lane Accuracy, Cornering**

Set up 100' radius, 90 degree corner with cones spaced at intervals of 5'. Navigate leader vehicle around the turn, at constant speeds of 7, 10, 15, 20 mph. Ensure ability of ATMA to maintain follow distance and lane accuracy around turn. Repeat with 75' and tighter radius corners if possible. After constant speed validation, validate accurate reaction of ATMA to both acceleration and deceleration of leader vehicle just before, during, and just after turning.

Use GPS data on leader and follower to determine follow distance.

Mount GoPro cameras on leader vehicle looking back, and on follower vehicle looking forward, for collection of qualitative data of variation in follower's path.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle, cones set up as a constant radius corner, GoPros and mounts.

12:00pm **Break for lunch.**

1:00pm **Scenario 10 – Tight Turn Situation**

Operate leader vehicle at tightest possible turn, note performance of ATMA in tight radius turn situation.

Use GPS data to determine path of follower vehicle, to ensure it does not deviate from lead vehicle's turn.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

2:00pm **Scenario 11 – Acceleration**

Perform startup rollout, upon follower vehicle reaching first e-crumb, accelerate lead vehicle in a straight line as quickly as possible to constant speeds of 20 and 25 mph.

Pull GPS data on leader and follower. Characterize effect of acceleration on follow distance, and delay time for follower to react to the acceleration.

Perform 3 scenarios for accuracy.

Compare follow distance changes during acceleration to the changes when ATMA is human-driven.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider/driver (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

3:00pm **Scenario 12 – Pulling Over**
Drive lead vehicle at typical striping operation speeds (~7mph). A cone will mark out a starting point for the vehicle to begin simulating pulling over to the side of the road. Check distance required for follower to also pull over and stop.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider/driver (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

4:00pm **Debrief Day 2, with conference call for offsite participants.**
Determine current progress and plan to conduct additional scenarios Thursday, June 29 if necessary.

Call Number: 1-877-820-7831, Code: 704136#

Thursday, June 29

Christman Field, Fort Collins

Determine Limitations and Predictability of ATMA Behavior in Atypical Operational Scenarios

7:30am **Conference call briefing with offsite interests.**

Call Number: 1-877-820-7831, Code: 704136#

8:00am **Layout of plan for day 3. Breakfast.**

Personnel: All CDOT Region 4 striping crew, Joe, Tyler, MSI Engineers, CSU student researchers.

8:30am **Scenario 13 – Maximum Speed Exceeded (NOT CURRENT CAPABILITY)**
If a maximum speed is able to be set (which CDOT thinks would be beneficial to safe operation), perform necessary modifications to add this max speed. If doable in short time, perform validation of this on track: take lead vehicle above maximum speed intended for ATMA to follow.

Pull speed/distance data to determine how long ATMA took to disconnect. Ensure ATMA does not exceed maximum speed before disconnecting.

Repeat scenario 3 times for accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

9:30am **Scenario 14 – Parking Brake Set**

Set parking brake in ATMA. Begin driving lead vehicle. Observe performance of ATMA. ATMA will not know that parking brake is set – for information purpose only, with approval of MSI engineers.

Pull GPS data on leader and follower to see if following distance remains the same.

Repeat scenario 3 times for accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

10:00am **Scenario 15 – Communications Loss**

Cut communications link between leader and follower vehicle. Does ATMA come to a stop or continue? Compare stopping time to noted emergency stop button distances and times. Adjust communications time-out setting if necessary.

Repeat scenario 3 times for accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

10:30am **Scenario 16 – GPS Loss**

Cut GPS Signal and observe performance.

If vehicle stops, record stopping distance data.

Repeat 3 times for accuracy.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

11:00am **Scenario 17 – Bump Steer**

Use same 10’ wide lane of cones to observe effect of bump steer on following accuracy. Create a bump using 2 4x4s, placed on only one side for follower vehicle to drive over.

Observe effect on lane accuracy. Tighten cones following successful performance validation.

Repeat minimum 3 times.

Repeat scenario around 100’ radius corner 3 times.

Record and plot GPS data to observe effect on follower vehicle’s path.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

12:00pm **Break for lunch.**

1:00pm **Scenario 18 – Simulated Impact**

(Only perform if it is possible without damaging sensor) Verify impact sensor behavior by applying the voltage associated with an impact across the sensor wires to simulate an impact.

Record stopping distance.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle, voltage source.

1:30pm **Scenario 19 – Sensor Disconnects**

For sensors that can be safely disconnected, check performance of vehicle with loss of sensor output. Consult with MSI engineers before continuing. If possible to simulate no steering ring, brake, or throttle actuation through CAN bus system, evaluate these system losses too.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

2:30pm **Scenario 20 – Slalom Course**

Set up slalom course with cones spaced 100’ apart in a straight line for 1000’. Repeat with different cone spacing if possible.

Observe behavior of ATMA as it follows leader.

Record following distance.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

3:00pm **Continue driving vehicle on track.**
Continue to put vehicle through acceleration, braking, cornering situations with MSI engineer on board collecting data. Ensure that vehicle continues to perform predictably.

Personnel: Lead vehicle driver (R4 striping), ATMA safety rider (R4 striping), MSI engineer riding in ATMA to record data.

Materials: Laptop and associated cables to interface to vehicle.

4:00pm **Debrief Day 3, with conference call for offsite participants. Set up for CDOT showing on Friday, June 30.**
Determine if additional track time is needed. Decide which scenarios are best to display the next day.

Call Number: 1-877-820-7831, Code: 704136#

Friday, June 30

Christman Field, Fort Collins

Debrief Week 1, Show vehicle to interested CDOT and partner agency personnel.

7:30am **Conference call briefing with offsite interests.**

8:00am **Setup of airfield for informational event.**

Personnel: All CDOT Region 4 striping crew, Joe, Tyler, MSI Engineers, CSU student researchers.

11:00am **Open cabs for people to look in vehicles, sample scenario demonstrations.**

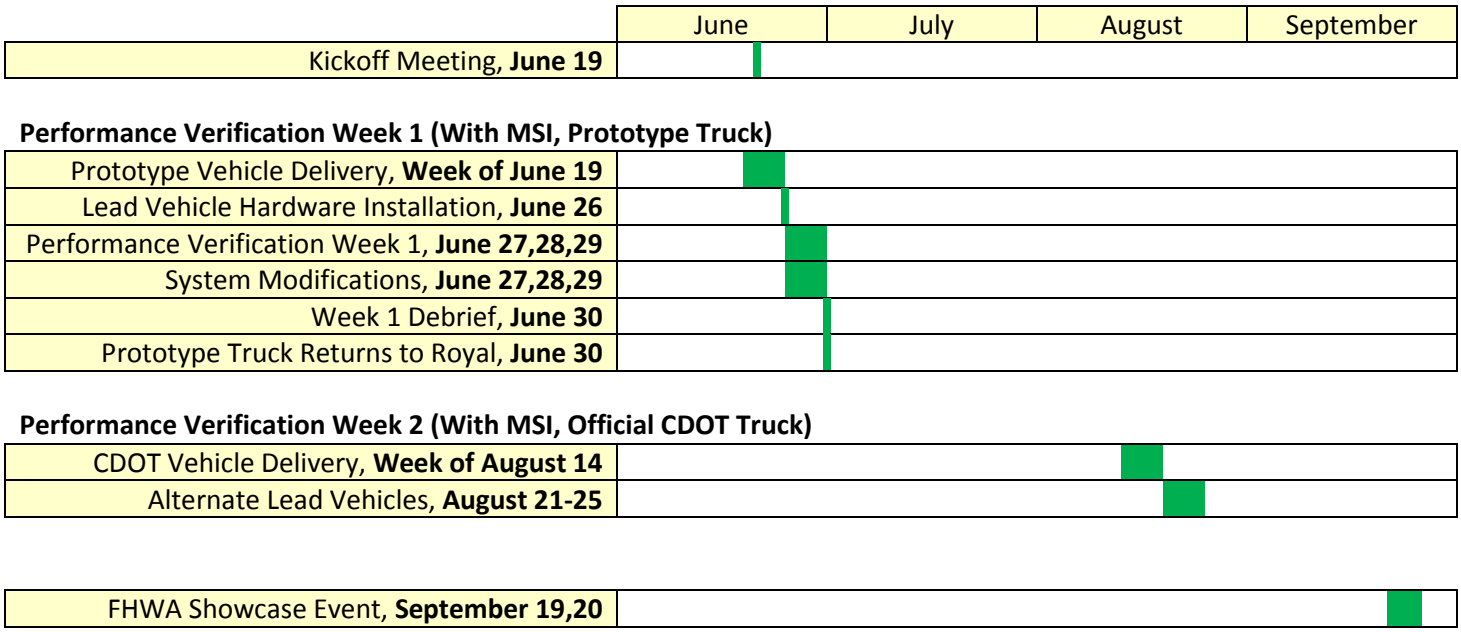
Conference Room, Fort Collins

9:00am **Debrief of week's activities.**
Discussion of verification results, lessons learned, and status of project compared to set goals. Discussion of next steps.

Vehicle Performance Verification Week 1 Material Needs and Responsible Parties

Cones, 300	Rod Dudley
150ft Tape Measure	Rod Dudley
Chairs, 15	Rod Dudley
Tables, 4	Rod Dudley
Generator	Rod Dudley
Shop Fan	Rod Dudley
Coolers, 2	Joe Meyer
Water	Joe Meyer
Ice	Joe Meyer
Snacks	Joe Meyer
Bagels	Tyler Weldon
Coffee	Tyler Weldon
Canopy	Joe Meyer
Storage Trailer	Rod Dudley
Drone	Rod Dudley
GoPro Cameras, 2	Joe Meyer
Mounts for GoPros	Joe Meyer
Professional Film Equipment	Stephen Martinez
Laptop	Glen Larmore
Vehicle Interface Equipment	Glen Larmore

Performance Verification and System Implementation Schedule Overview



ATMA Project Goals

Goal 1: Installation of system and successful following of CDOT striping truck.

- The system must be installed in a CDOT striping truck and be shown to function.
- Train CDOT crews for eventual use in operations.

Goal 2: Identification of limitations and anomalies in track testing.

- Builds understanding of the vehicle's limitations.
    - Braking and safety systems performance, following capability performance, and operational predictability.
- Identified anomalies will allow for improvement of system before road use.

Goal 3: Log open highway miles of ATMA in CDOT striping operations.

- Striping operations provide a perfect opportunity for realizing increases in both safety and efficiency through use of the autonomous-capable TMA.
- As the vehicle is continually driven, it will encounter new scenarios and limitations that will provide data to continually upgrade the system, building up the technology for use in operations of increasing complexity.

Goal 4: Prove interchangeability of lead vehicle system through installation on a sweeper and a mower.

- Multiple CDOT operations can benefit from this technology and the first step is to prove the compatibility and interchangeability of the system.

Additional Decision Points and Milestones Outside the Project Scope:

- Long-term insurance
- Complete removal of safety rider
- Changes to system based on test results