Automated Vehicles and Adverse Weather – Phase 3

Source: FHWA

Atmospheric and road weather conditions can adversely affect vehicle and driver behavior. The Automated Vehicles and Adverse Weather – Phase 3 project sought to identify how automated vehicles (AVs) -- i.e., vehicles with automated driving systems will detect and react to adverse weather and road weather conditions, as well as different traffic scenarios. Two rounds of field tests were conducted to challenge AV perception systems with artificial and controlled adverse weather and different traffic/roadway configurations at a controlled outdoor laboratory setting. The first round of field tests were conducted in the Spring/Summer of 2020, and the second round of field tests were conducted in the Winter of 2020/21. Both field tests were conducted at Transportation Research Center, Inc. (figure 1).

Figure 1. Transportation Research Center Inc. Source: Google Maps, 2021. Transportation Research Center Inc. 1:23,000. Google Maps [online] Available through: https://goo.gl/maps/MPmrRCo1ph8EZfqn6 [Accessed 10 June 2021].

Summer Field Test #1

The first round of field testing was performed during the week of June 6, 2020, at the Skid Pad test facility (as indicated by the top arrow in figure 1). This facility has seven 12-ft- wide lanes that run adjacent to a set of crosswind generators (figure 2).

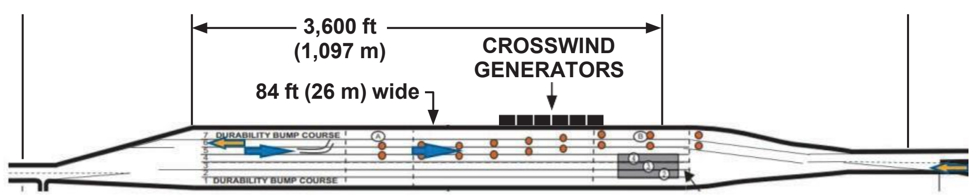


Figure 2. Summer Field Test #1 Test Track Layout. Source: FHWA

Two production vehicles with differing perception systems were driven through a planned variety of road and road weather conditions to permit an assessment of how well each automation feature performed. For all test runs, the test vehicles were driven at 45 mph and engaged with Lane Centering Assist before entering the emulated scenarios. A minimum of seven runs were conducted for each scenario.

Test Vehicles' Capabilities

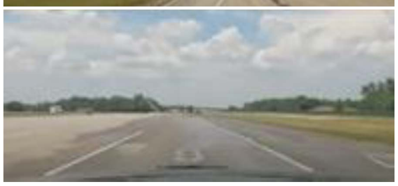
Vehicle	Sensors	Driver Assistance Systems
Summer Field Test #1 Vehicle A	• eight video cameras including rear, side, and forward • forward radar antenna • 12 ultrasonic sensors	• adaptive cruise control • lane centering assist
Summer Field Test #1 Vehicle B	• 2 HD cameras • 1 360° lidar • 1 forward facing and 2 rear corner radar	• adaptive cruise control • lane centering assist • lane departure warning

Scenarios Tested

Work Zone Lane Change with Barrels. Barrels were placed on either side of the test lane to emulate a Work Zone requiring a lane change – the test vehicle had to shift a full lane width across a solid lane line. During each run, the test vehicles proceeded through the barrel-lined area to determine if the vehicle systems allowed the desired lane change.

Pavement Markings with Brake Marks. A pair of emulated diverging brake marks were placed across the travel lane lines. During each run, the test vehicles proceeded through the area with brake marks to determine if the vehicle systems were able to maintain lane centering.

Work Zone Lane Closure with Lane Markings. An on-ramp merging into a t ravel lane was used for emulating a Work Zone lane closure. During each run, the test vehicles proceeded through the closing lane to determine if they were able to detect the closing lane and perform a lane change maneuver.



Pavement Markings with Disappearing Shoulder. A travel lane with a left lane line that disappeared over a span of 100 ft was used in this test scenario. During each run, the test vehicles proceeded through the travel lane to determine if the vehicle system was able to maintain lane keeping.

Source for scenario pictures: FHWA

Weather and Road Weather Conditions Tested

All scenarios were tested under clear, daytime, with a dry roadway (Baseline); daytime wet roadway with sun glare; and nighttime wet roadway with night glare conditions. Additionally, the Work Zone Lane Change with Barrels scenario was tested under crosswind conditions.

Key Takeaways

1. Limitations of the test vehicles were successfully challenged through exposure to adverse weather conditions (figure 3).
2. A potentially significant amount of inconsistency in the test vehicles' performance was found, both across vehicles and between runs for a single vehicle. Summer Field Test #1 Vehicle B produced better performance than Summer Field Test #1 Vehicle A. (figure 4).
3. Sizeable differences in the test vehicles' approaches to automation and driver assistance functionality were evident.

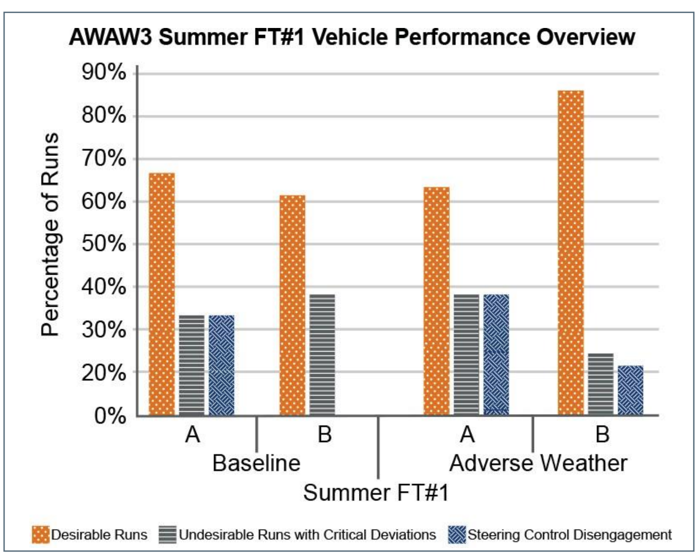


Figure 4. Summer Field Test #1 Vehicle B producing more desirable runs than Summer Field Test #1 Vehicle A during Summer/Spring weather conditions. Source: FHWA

Figure 3. Nighttime glare conditions covering lane lines and creating perception challenges for test vehicles during Summer Field Test #1. Source: FHWA

4. In real-world conditions, a vehicle's ability to complete the expected maneuvers in a majority of scenarios might lead to driver over-trust and over-confidence in the abilities of automated systems. This may lead to distracted driving, complete disengagement, and an inappropriate use of automation (i.e., reliance on automation in complex situations that were not listed or listed as exceptions in the owner's manual).

Winter Field Test #2

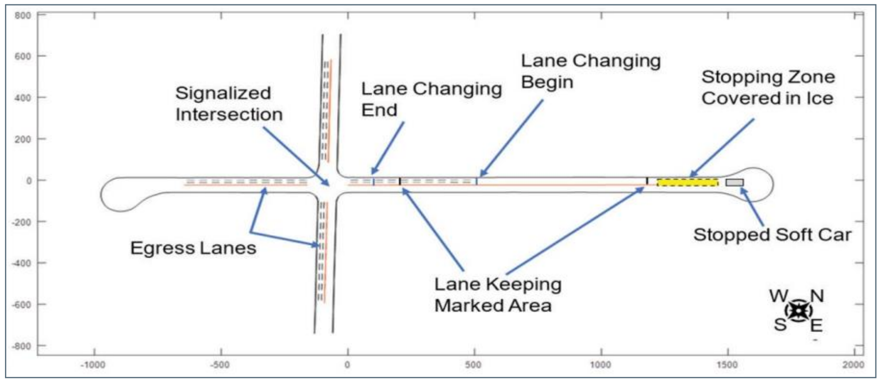


Figure 5. Winter Field Test #2 Test Track Layout. Source: FHWA

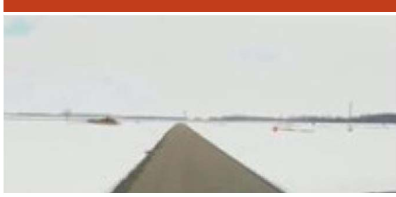
The second round of field testing was performed between January 28 and March 3, 2021, at the Smart Mobility Advanced Research and Test Center test facility (circled in figure 1). The test track has a signalized intersection with six 12-ft-wide lanes on all four approaches (figure 5).

Two test vehicles with different perception systems were driven through a variety of weather and road weather conditions to assess how well each perception system assessed the scenario. One commercially-available passenger car (Winter Field Test #2 Vehicle A) had SAE Level 2 automation capabilities and one non-commercially- available passenger car (Winter Field Test #2 Vehicle B) had SAE Level 3 capabilities. Winter Field Test #2 Vehicle B was equipped with aftermarket sensors and open-source automated driving system software. Based on the weather conditions, the test vehicle speeds were varied across the scenarios between 15 to 45 mph to ensure safe driving conditions.

Test Vehicles' Capabilities

Vehicle	Sensors	Driver Assistance Systems
Summer Field Test #1 Vehicle A	• eight video cameras including rear, side, and forward • forward radar antenna • 12 ultrasonic sensors	• adaptive cruise control • lane centering assist • traffic jam assist
Summer Field Test #1 Vehicle B	• 2 HD Cameras • 1 360° lidar • 1 forward facing and 2 rear corner radar	• localization via lidar HD map • coordinated path following (only this vehicle could perform left turns)

Scenarios Tested



Lane Keeping. Snow-covered, plowed, and ice-covered roadway conditions from natural snowfall were used to emulate winter road weather conditions on arterial and neighborhood roads. Lane lines were covered in each test run. During each run, the test vehicles proceeded through the marked area to determine if they could maintain lane keeping.

Right Lane Change. Snow-covered and plowed conditions from natural snowfall were used to emulate winter road weather conditions where vehicles may have to exit from the roadway. During each run, the test vehicles proceeded through a marked area to determine if they could change lanes.

Green at Signalized Intersection. A signalized intersection with snow-covered and plowed conditions from natural snowfall was used to emulate intersections on arterial and neighborhood roads. The test vehicles were driven through a signalized intersection with a green light to determine if they could perform the through (Vehicle A) and left turn maneuver (Vehicle B).

Stopped Car Detection. This scenario was designed to emulate a stopped car in an ice-covered stopping zone. The travel lane's stopping zone was covered in ice and a soft car was placed where the test vehicle was intended to stop. The desired maneuver was for the test vehicle to stop, within the ice-covered stopping zone, without deviating outside of the lane lines of the travel lane.

Source for scenario pictures: FHWA

Weather and Road Weather Conditions Tested

All scenarios were tested under Baseline conditions: clear, daytime, and a dry roadway. Lane Keeping, Right Lane Change, and Green at Signalized Intersection scenarios were tested under snow-covered and plowed roadway conditions. Lane keeping and Stopped Car Detection scenarios were tested under ice-covered roadway conditions.

Key Takeaways

1. Limitations of the test vehicles were successfully challenged through exposure to adverse weather conditions (figure 6).
2. A potentially significant amount of inconsistency in the test vehicle performance was found, both across vehicles and between runs for a single vehicle. Inconsistencies included:
    - Localization loss – Winter Field Test #2 Vehicle B estimated excessive deviation from its pre-programmed travel path due to loss of localization (figure 7)
    - Rapid accelerations and decelerations at snow-covered intersections
    - Inability to drive close to centerline on roadways with varying snow depths
3. Winter Field Test #2 Vehicle B was able to capture, assess, and react to adverse weather and road weather conditions more efficiently than Winter Field Test #2 Vehicle A (figure 8).
4. Sizeable differences in the test vehicles' approaches to automation and driver assistance functionality were evident. For example:
    - One test vehicle relied on a camera-based perception system (Winter Field Test #2 Vehicle A) and the other vehicle relied on a lidar and HD map-based perception system (Winter Field Test #2 Vehicle B). As a result, both vehicles used different approaches for the following aspects:
        - Sensing and processing environment setting and controlling automation
        - Algorithm-based criteria for automation support
        - Ways of presenting status and alert information to drivers
5. The need for redundant sensing systems in test vehicles was evident:
    - During certain winter conditions, the test vehicles lost localization, disengaged steering control, and critically deviated from the desired paths.
    - Redundancy in perception, steering control, localization, braking, actuation, and other systems is essential to successfully operate vehicles with automated driving systems under all weather, road, and environmental conditions.

For detailed test results and findings from AVAW3, please refer to the AVAW3 Final Report (FHWA-HOP-21-047).

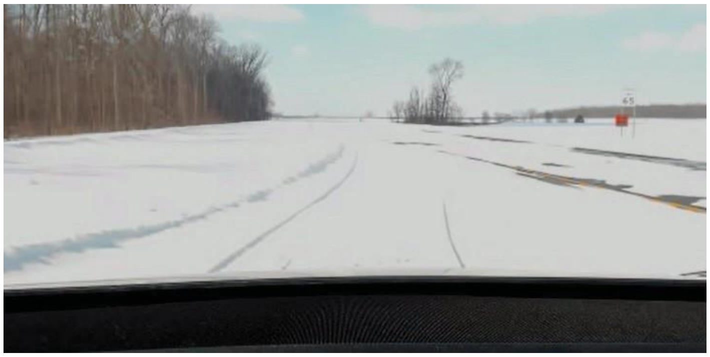


Figure 6. Winter Field Test #2 Vehicle A following the piled up snow in the travel lane and deviating to the adjacent lane. Source: FHWA

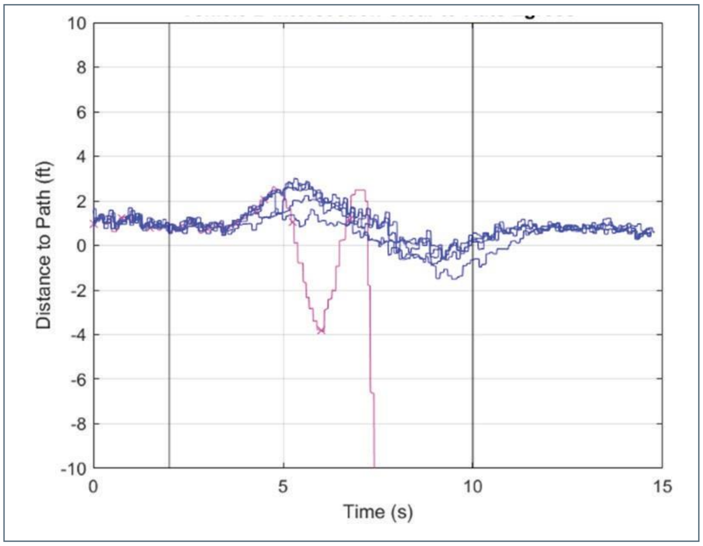


Figure 7. Winter Field Test #2 Vehicle B's estimation of excessive deviation from the travel path due to loss of localization, as indicated by black line with x symbol. Source: FHWA

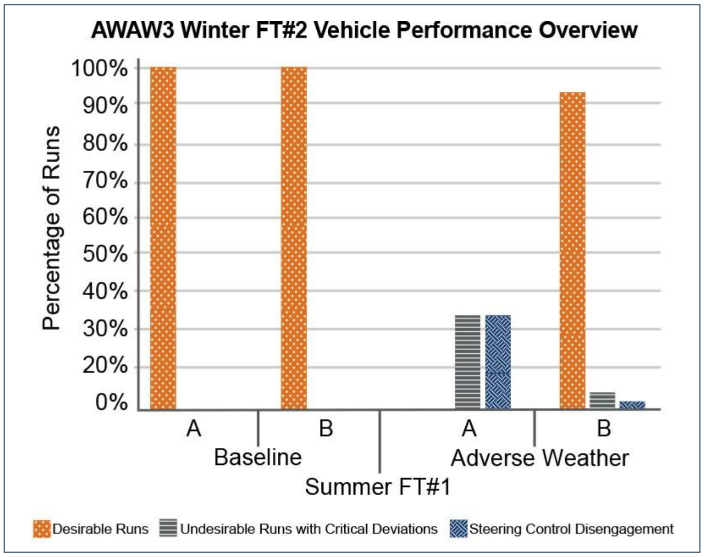


Figure 8. Winter Field Test #2 Vehicle B producing more desirable runs than Winter Field Test #2 Vehicle A during adverse winter weather conditions. Source: FHWA

Interested in Learning More About This Project?

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