DriveOhio

Ohio Rural Automated Driving Systems (ADS) Project

Final Evaluation Report

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Acronyms and Abbreviations

3D	three-dimensional
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AEB	Automatic Emergency Braking
AWS	Amazon Web Services
CE	controlled environment
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	high definition
HMI	human machine interface
I	Interstate
IMU	inertial measurement unit
INS	inertial navigation system
kbps	kilobits per second
KPI	Key Performance Indicator
LEIP	Law Enforcement Interaction Plan
LiDAR	Light Detection and Ranging
mph	miles per hour
NOFO	Notice of Funding Opportunity
ODE	Operational Data Environment
ODOT	Ohio Department of Transportation
OSHP	Ohio State Highway Patrol
OU	Ohio University
ROS	Robot Operating System
RTK	real time kinematics

S3	Amazon Simple Storage Service
SAE	SAE International, formerly Society of Automotive Engineers
SMP	Safety Management Plan
SR	State Route
TRC	Transportation Research Center
UC	University of Cincinnati
UCLA	University of California Los Angeles
USDOT	United States Department of Transportation
VRU	vulnerable road user
YSU	Youngstown State University

Executive Summary

In early 2020, the U.S. Department of Transportation (USDOT) awarded an Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of the Ohio Department of Transportation (ODOT). The Ohio Rural ADS Project examined how automated vehicles perform in rural settings over a 4-year project. In parallel deployments, the Ohio Rural ADS Project operated two vehicle sets (light-duty passenger vehicles and heavy-duty tractors) with prototype ADS technology. After Controlled Environment (CE) tests were conducted per the CE Test Plans and documented in CE Test Reports, both vehicle sets deployed for 7 to 10 months on public roads in Ohio. Throughout both deployments, the project team gathered vehicle operational data to measure vehicle performance. The data was stored in cloud-based Amazon Web Services (AWS) including Simple Storage Service (Amazon S3) and is available to assist researchers involved in vehicle automation for at least the next five years.

Supply chain disruptions stemming from the COVID-19 pandemic led the project team to innovative approaches in the purchase/lease and initial use of vehicles and the automation technology to be demonstrated. Since two types of vehicles (passenger vehicles and Class 8 tractors) were available through organizations participating in the project, the team was able to perform initial prototype testing for the passenger vehicles and complete truck platooning testing, which enabled deployments to be conducted during the last year of the project. The project team selected Apollo Level 3 software for the passenger vehicles on two Ford Transit vans and one Chrysler Pacifica van and used Bosch's truck platooning prototype system on two Class 8 Navistar tractors.

In the truck platooning deployment, Ohio-based motor carrier firm, EASE Logistics, used the two Class 8 tractors in revenue service (hauling clients' freight) driving with automation for 11,486 miles without safety incidents and while truck platooning for 5,050 of those miles. Three passenger vehicles drove 3,822 miles on three rural and small-town urban routes near Athens, Ohio (68.3 percent of those miles in Level 3 automated mode) using high-definition (HD) maps without a safety incident on the three project-designated public road routes. The EASE Logistics truck drivers were trained by the project team and had good experiences with the prototype truck platooning technology, which EASE Logistics hopes to use again in the future. The passenger vehicles had trained, 3-person driver teams from project team members, Transportation Research Center (TRC) and Ohio University (OU). The driver teams helped operate the automation software and data collection system and recorded their observations about reasons for disengagements of the automated system which occurred frequently during deployment runs. Important feedback was provided to the project team by both the truck and passenger vehicle drivers on the vehicle operations and their interactions with other road users.

Both deployments collected data at less than one second intervals when the prototype automation software was running. The data included vehicle operations such as speed, acceleration, steering wheel angle, and GPS data with time stamps. The tractors uploaded data during the trips while the passenger vehicles stored the data on-board and uploaded the data after the trip. In both deployments, metadata was added, and the data was converted to an Amazon DynamoDB database for storage and analysis. For truck platooning and adaptive cruise control (ACC), the tractors used radar. The radar data was timestamped and uploaded with video data from on-board cameras to storage. The passenger vehicles had radar and light detection and ranging (LiDAR) that were used for object identification and path following. That data was also timestamped and uploaded. ODOT provided cloud storage on AWS that was used by the project team for collaborating and analyzing data and can be used by other vehicle automation researchers.

Both deployments provided interesting insights into truck platooning and passenger vehicle automated vehicle prototype technologies. The Bosch truck platooning prototype software, as well as the Apollo Level 3 ADS software, often experienced start-up problems or early on and off experiences which meant recording of very short trips or more system disengagements than were desired. Disengagements were common with the passenger vehicles, especially around other traffic and pedestrians in small town urban areas on parts of the project-designated routes. Through safety driver inputs, the project received large amounts of data about reasons for disengagement that can be analyzed with timestamps and location data. This will provide researchers with detailed information about where and why system disengagements occur. The tractors recorded information about cut-ins and the behavior and response of both the drivers and the system to such actions by other vehicles. Including deployment routes with variable speed limits was important in assessing ADS performance. In rural areas along three designated routes, surrounding traffic often drove above the speed limits; while in urban areas traffic sometimes kept the speed below the speed limit which the ADS system wanted to travel. Purple lights (called chicken lights) located on both sides of the truck platooning-capable tractors were requested by Ohio State Highway Patrol (OSHP) and were lit during automated operations. The OSHP also suggested that such lights be standardized and required in the future for automated vehicles. Based on the passenger vehicle deployment, the project recommends refinement to the HD map process to better account for the variety of road conditions and speed limits. Coupled with improvements in detection of both large and small objects (vehicles or pedestrians), the project team is hopeful that the data collected, and results described in this report are useful in the continued development and improvement of ADS technologies.

1.0 Introduction

1.1 Background and Objectives

In early 2020, the U.S. Department of Transportation (USDOT) awarded an Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of the Ohio Department of Transportation (ODOT), JobsOhio, Transportation Research Center (TRC), Bosch, Ohio University (OU), University of Cincinnati (UC), Youngstown State University (YSU), and Southeast Ohio community partners. The Ohio Rural Automated Driving Systems Project (Ohio Rural ADS Project) examined how automated vehicles perform in rural settings. In parallel deployments, the ADS Project had two vehicle sets (light-duty passenger vehicles and heavy-duty tractors). Figure 1 shows the two types of deployments.

FIGURE 1 – AUTOMATED DRIVING SYSTEMS DEPLOYMENT TYPES

1.1.1 Heavy-Duty Trucks

The intent of the truck portion of the project was to test two Class 8 automated tractors with semi-trailers in Ohio, using prototype truck platooning technology (capable of Level 1+ automation per the SAE International levels of automation). The project's truck platooning system includes driver support features such as ACC and other related technologies to support truck platooning operations. Truck platooning involves two tractors, with semi-trailers, traveling closely together in a cooperative manner, which can improve safety and fuel efficiency. The truck platooning system relies on radar and cameras to enable lane centering and platooning functionality. The two Advanced Driver Assistance System (ADAS) tractors required that the driver always be engaged with the driving task. These tractors underwent controlled environment (CE) tests at the TRC SMARTCenter test facility per a CE Test Plan developed by the project team and a risk assessment conducted by Bosch per its normal prototype product delivery and release processes. Additionally, the two-truck platooning capable tractors were driven by TRC professional drivers over two specific routes to further test the truck platooning technology on public roads before delivery of the tractors to the Ohio-based motor carrier firm, EASE Logistics, for in revenue service.

1.1.2 Light-Duty Passenger Vehicles

The intent of the passenger vehicle portion of the project was to test prototype automated passenger vehicles on public roads in the Athens, Ohio area with prototype Level 3 automation features per the SAE

International levels of automation. Two Ford Transit vans (operated by TRC) were subject to testing at the TRC Test Track near Marysville, Ohio and one Chrysler Pacifica van (owned by OU) was subject to testing at and around the Ohio University campus in Athens, Ohio. CE tests, per the CE Test Plans, were conducted and documented in CE Test Reports.

1.1.3 Data Collection

The truck platooning deployment by EASE Logistics, with its own drivers, gathered vehicle operational data in single-truck and truck platooning modes. The data gathered enabled the project team to calculate performance measures. This data is available for analysis of potential safety and efficiency benefits of the technology and will assist researchers involved in vehicle automation well into the future.

Likewise, the goal of the passenger vehicle deployment was vehicle data collection. Four Level 3 vehicles collected data on three project-designated public road routes in southeast Ohio. There were two Ford Transit vans operated by drivers from TRC, a Ford Fusion owned by TRC which was used in the initial CE testing of the project and then again in limited operation around Athens, and one Chrysler Pacifica van owned by OU and operated by drivers from OU. None of the vehicles carried passengers other than project team operators and field support team members involved with driving or data collection. The data collected on each vehicle trip during the deployment was uploaded to a cloud server and is available to researchers.

1.2 Vehicle Acquisition Impact of COVID-19

The project started during the COVID-19 pandemic in early 2020. After contract award in April 2020, the project team met virtually and drafted planning documents. An immediate issue that adversely affected both the passenger vehicles and tractors was the limited ability to purchase/lease new vehicles (both vans and tractors). New Transit vans were not available for purchase until the second year of the project. Leasing of two tractors was similarly affected. Supply chain shortages led the project team to find other ways to procure vehicles. Project team member TRC had a Ford Fusion and Bosch had a Class 8 tractor which were both provided for deployment in the project. The TRC Fusion was equipped with Autoware software and ADS components provided by AutonomouStuff.

1.3 Project Organization, Stakeholders, Responsibilities, and Contributions

The prime contractor, DriveOhio, is a division within ODOT that manages development and research projects for smart mobility technologies, including automated vehicles. The project partners and their primary roles are listed below.

- TRC operated the test facility, tested both the tractors with semi-trailers and passenger vehicles, and then drove the passenger vehicles in deployment on the project-designated routes near Athens, Ohio.
- OU tested and deployed the Pacifica van on the Athens routes, developed the scripts for converting raw operations data to databases for subsequent analysis, converted all deployment data on the ODOT cloud storage space, and analyzed the passenger data.

- AutonomouStuff provided the Autoware and Apollo software and sensors for the passenger vehicles and provided technical assistance to TRC and OU throughout the project.
- Bosch provided the truck platooning software and hardware as well as the computer environment to process the collected data and worked closely with EASE Logistics in providing technical assistance and analysis of data and performance measures.
- University of California Los Angeles (UCLA) provided technical assistance throughout the project including creating maps that could be used in the Fusion deployment in Athens.
- UC led the Institutional Review Board effort that examined personal data in the early phases of the project.
- YSU students worked with passenger vehicle data from the project and shared preliminary analysis and graphics with the project team.
- CDM Smith and its subcontractors, Michael Baker, Brainlikes, and Murphy Epson, assisted DriveOhio with project management, public relations, and worked with all partners in creating program deliverable documents.
- ODOT headquarters facilitated cloud storage and related services. The project coordinated closely with ODOT District 10 in the Athens area and with the Ohio State Highway Patrol (OSHP) so that they were aware of the public road deployments.
- As needed throughout the project, the team engaged stakeholders including:
    - Local technical officials – county garages, city/county engineers, emergency medical services
    - Logistics organizations (Dayton and Columbus, port authorities, etc.)
    - Local community officials – elected officials, community organizations
    - Individual Supply Chain players (e.g., Navistar)
    - Law Enforcement stakeholders (OSHP, sheriff/local law enforcement)

Section 4 includes details about stakeholder engagement and feedback.

1.4 Vehicle Deployments

After successful CE testing for both tractors and passenger vehicles, all vehicles were operated on public roads in Ohio. While awaiting industry access to new Transit vans, TRC deployed the Fusion on public roads in the Marysville, Ohio area in the spring of 2022. The Transit vans were received in early 2022, outfitted with Apollo software, tested at TRC, and then deployed in the Athens, Ohio area from July 2023 through February 2024. The Pacifica van deployed on the same Athens routes from August 2023 through early December 2023. Considerable effort was involved in deciding on the three diverse rural routes in the Athens area, shown in

Figure 2. More detail about the project-designated routes is included in Section 3 along with discussion of the deployments on the various routes.

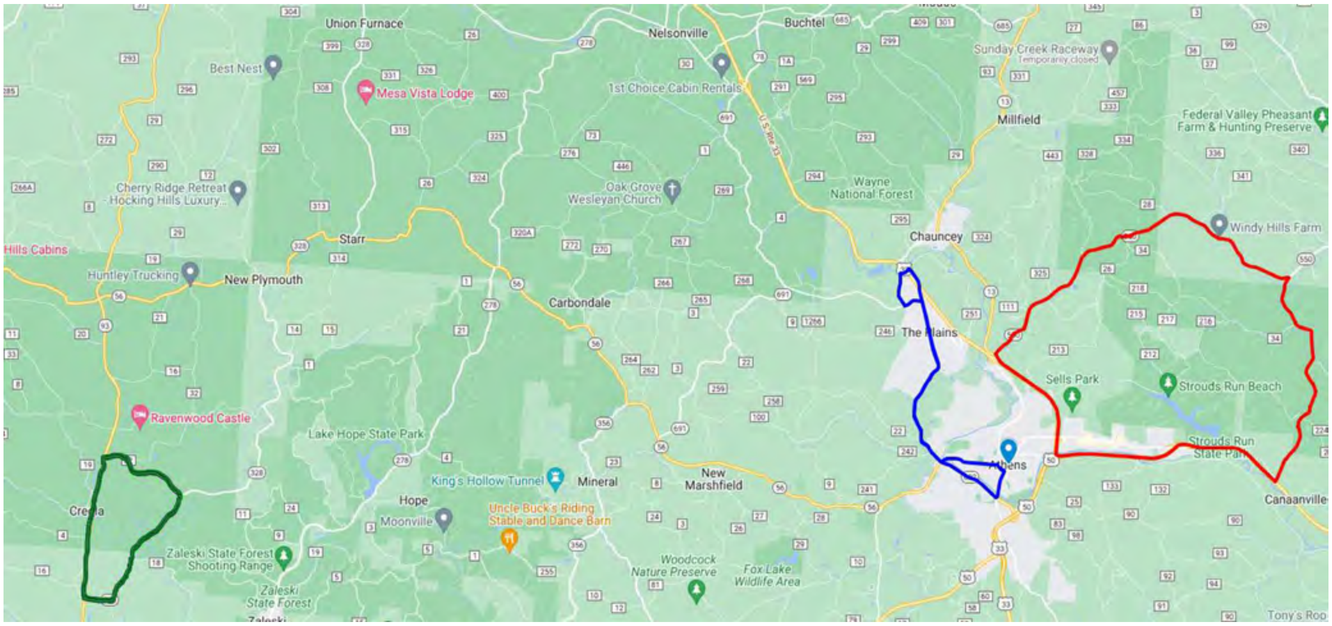

FIGURE 2 – PASSENGER VEHICLE AUTOMATION DEPLOYMENT AREA ROUTES
Source: Google, DriveOhio

EASE Logistics operated the two-truck platooning capable tractors in its revenue service (hauling client freight) on selected routes including Interstates, U.S. divided highway routes, and 2 lane routes in Ohio. It operated in single-truck and truck platooning modes for 7 months. The selected truck platooning routes reflect the project's Safety Management Plan (SMP) requirements as well as EASE Logistics working with its clients' business needs, as shown in Figure 3. Additional details are included in Section 2, along with discussion of the EASE Logistics truck operations. Results and observations related to passenger vehicle deployments near Athens, Ohio are discussed in Section 3.

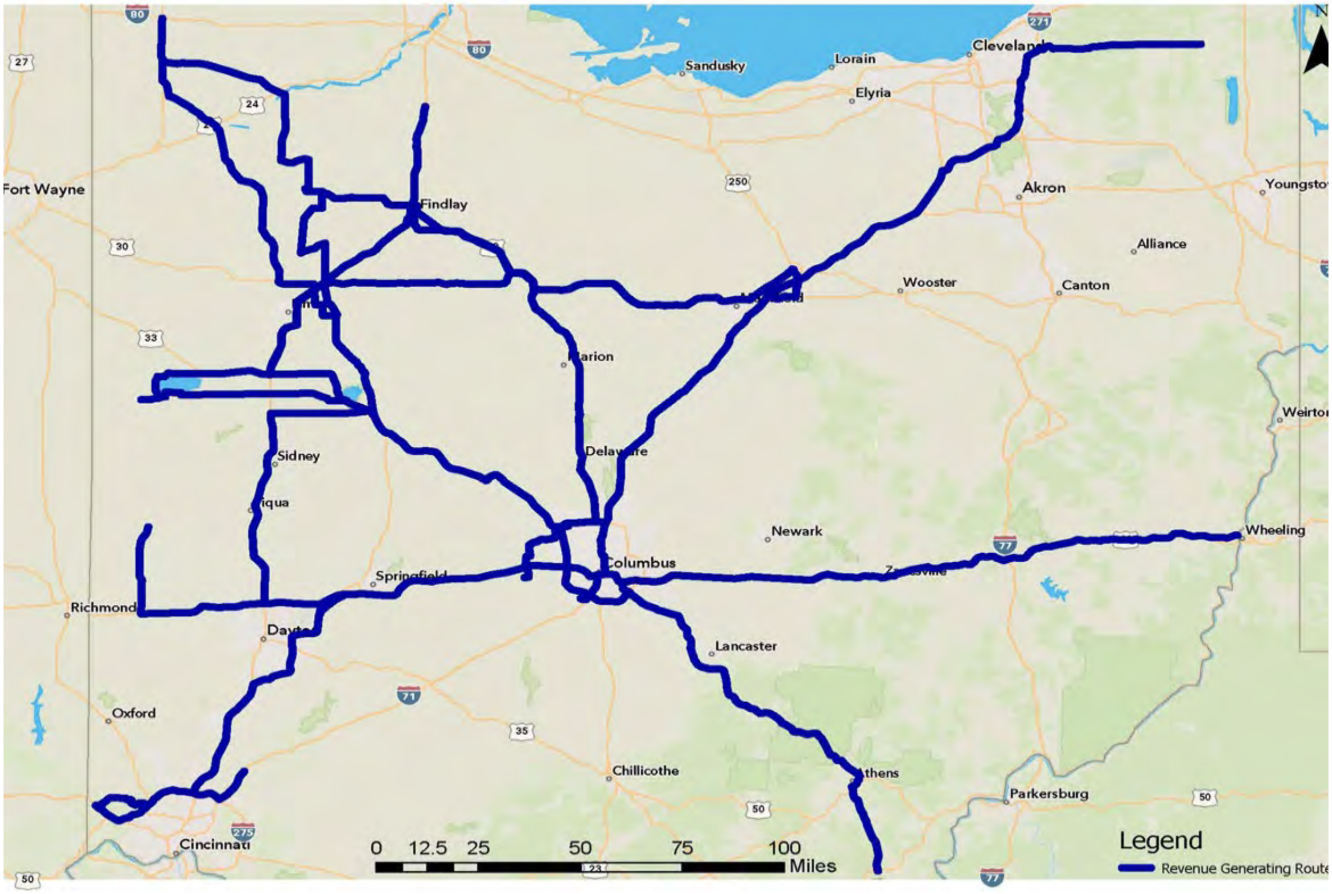

FIGURE 3 – PROJECT SELECTED TRUCK PLATOONING ROUTES

1.5 Report Structure

Section 2 describes the truck platooning technology installed on the two tractors. It describes performance metrics used and explains the data collected and how it was prepared for researchers and data analysts. Section 2 describes the testing of the tractors at TRC and includes feedback from EASE Logistics and law enforcement about the truck deployments in revenue service.

Section 3 describes the passenger vehicle technology, CE test results of both Autoware and Apollo software stacks, and routes that were selected for the passenger vehicle deployments. Section 3 describes the data collected, examples of performance metrics considered, data analysis conducted, and overall results of the deployments. It also includes observations of the vehicle drivers during the deployments.

Section 4 includes information about focus group meetings with stakeholders who observed either or both the truck and passenger vehicle deployments.

Section 5 summarizes the results and identifies key conclusions and takeaways from the project.

2.0 Truck Platooning Technology Deployment

2.1 Truck Platooning Technology Description

For the trucking deployment portion of the project, ADAS Level 1 truck platooning technology was implemented on two Class 8 tractors to travel together. The prototype truck platooning automation technology can control both steering and accelerating/decelerating, but the driver has the responsibility for the tractor and can take control at any time. The intent of the project was to test two platooning-capable tractors and then deploy them with an Ohio-based trucking company to use in revenue service on Ohio public roads. The truck platooning technologies on the two tractors included:

- Camera and radar system
- Vehicle-to-Vehicle communications using C-V2X
- Bosch Platoon Controller hardware and software
- Bosch Vehicle Motion Control System
- Lane Keeping
- Market-approved automated emergency braking
- Cooperative ACC (two tractor, semi-trailer platooning set)
- Human machine interface (HMI) with data in platooning mode for the driver in each tractor
- Forward radar (collision avoidance/ACC) & cameras (lane center)

A vehicle-to-vehicle communication channel was used to provide position, acceleration, and brake information for the following tractor. The following tractor was equipped with radar and could measure the distance, speed, and acceleration/deceleration, and if needed perform control interventions with very low latency based on operations in the leading tractor.

Truck operating data was collected in two forms: an Axis F Series video camera, streaming directly to ODOT's data environment on AWS via Amazon Kinesis video streams and continuous J1939 and Private CANbus data collected on an on-board computer and uploaded to Fleet Explorer Operational Data Environment (ODE) where the data was decoded before being sent to ODOT's Amazon S3 bucket for storage and future analysis. The CANbus data is the global standard for in-vehicle communications and has addressable messages and synchronous protocol for prioritizing message delivery. J1939 is a further standardization of a CANbus specifically for heavy-duty trucks and specifies bus physical and timing parameters, addressing standards, and Parameter Group Numbers message types. The tractors in the project used the J1939 recommended 500 kilobits per second (kbps) data rate for heavy-duty vehicles. The J1939 public bus is the main method for communication in a truck and is the tractor's primary source of information about its operation.

Bosch provided prototype truck platooning hardware and software capability and the data collection system (Appendix A1), as shown in Figure 4. During the project, Bosch upgraded and renamed Fleet Falcon to Fleet Explorer.

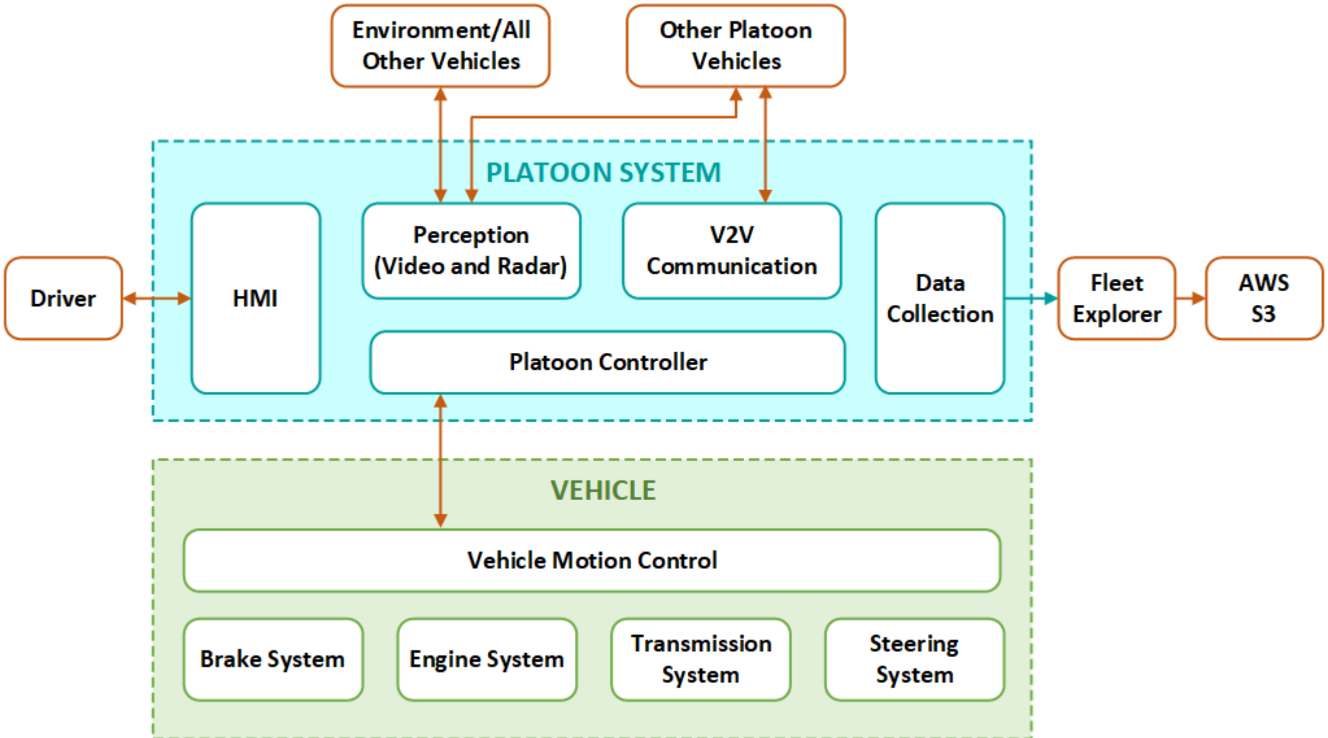

FIGURE 4 – TRUCK AUTOMATION FUNCTIONAL DIAGRAM

As depicted in Figure 5, whenever the vehicle is in operation, the vehicle streams operational data including baseline measurements of location, speed, acceleration, steering wheel position, and odometer and similar truck operations data. While in truck platooning mode, the data collected includes platoon active, the actual and target time headway, the target acceleration and brake status, and the cruise control speed among others. A more complete list of collected data is contained in the Interface Control Document (Appendix A2).

The two tractors had their own on-board computers that streamed data directly to the separate and intermediate Bosch Fleet Explorer ODE in the center box before being transferred to the ODOT's AWS environment for analysis and storage.

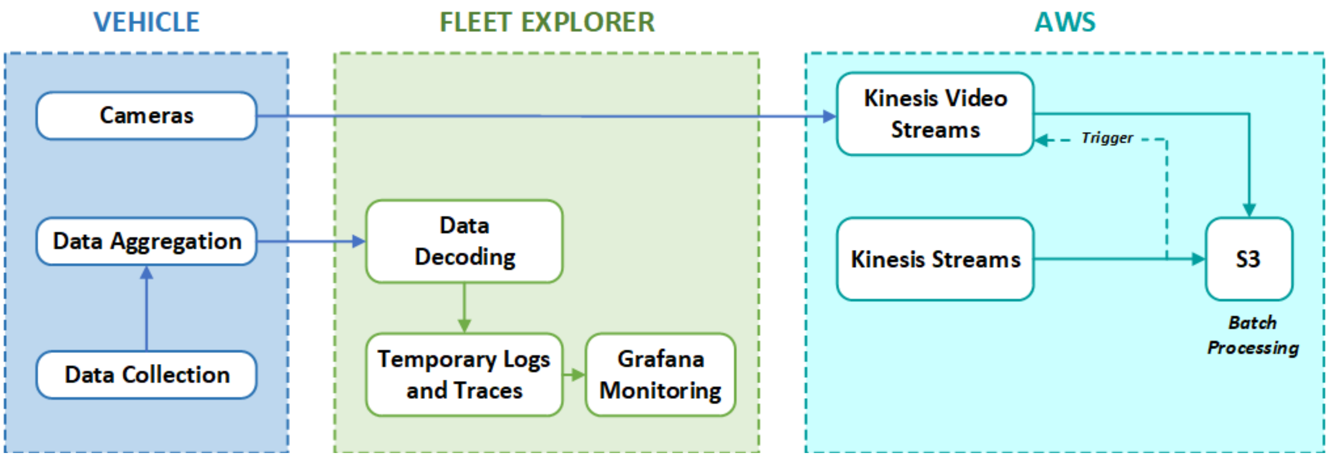

FIGURE 5 – TRUCK PLATOONING DATA FLOW

Streaming data was collected and uploaded to Fleet Explorer using protocol buffers. In intermediate processing of streaming data, Fleet Explorer decoded binary data using the appropriate metadata description files. This data was then re-encoded and had timestamps inserted into a time series database for operational monitoring and support and transmission to Amazon S3 using an Amazon Kinesis stream. Video data was sent directly from the vehicle to Amazon S3 using Kinesis Video Streams. A Lambda processor monitored the incoming stream from Kinesis, inserted timestamps in Amazon DynamoDB, and calculated project metrics (described in Section 2.6).

Because of equipment shortages in 2020, the project leased one new Class 8 Navistar tractor and one used Class 8 Navistar tractor from Bosch. Project personnel made the decision that the new Navistar would be the following tractor and the Bosch-owned older Navistar be the lead tractor.

The deployment of the two tractors on Ohio public roads with truck platooning technology lasted from September 2023 until February 2024. EASE Logistics operated and collected vehicle operating data using the two-truck platooning-capable tractors in revenue service on Ohio public roads. EASE Logistics had responded to a request for proposals from ODOT and used the two tractors in both single and platooning mode. The route selection was based on the SMP requirements as well as EASE Logistics' client needs. EASE Logistics' drivers had input into the use of the truck platooning technology. EASE Logistics gained approval from each client to use the technology. The goal of this project was to test a prototype truck platooning system in revenue service on public roads by a motor carrier firm while operating legally within existing state regulations. Therefore, the hauls were limited to Ohio and served EASE Logistics' clients with origin-destinations within Ohio which resulted in relatively short distance hauls.

2.2 Overview of Truck Platooning Tractor Tests

Bosch installed its truck platooning technology on the two tractors and conducted in-house tests that met Bosch's prototype technology internal release process. After these tests, the tractors were tested at the TRC SmartCenter's test track using a CE Test Plan. After the CE testing was conducted, Bosch reviewed the results using its prototype technology internal release process and released the truck platooning capable tractors to EASE Logistics for hauling in revenue service freight on Ohio public roads (see Appendix A3 for more detailed information).

During the CE testing, several tests were conducted to understand the underlying performance of the different subsystems including software initialization, brake performance, localization accuracy, lane keeping assist support, automated emergency braking (AEB), and standard ACC. A second round of testing was completed after changes were applied to how the AEB system interacted with the truck platooning system. After addressing different aspects of how the platooning system interacts with the underlying system, testing was done to work up to testing the full truck platooning system. This started by testing platoon formation and disengagement, before moving on to steady state platoon operation and platoon operation with a variety of speeds carried out by the lead vehicle. These tests were meant to ensure the platoon would deactivate as expected if either truck disengaged or when either truck changed lanes. The TRC team also tested disengaging after a cut-in or with hard deceleration. During the test, cut-ins did not disengage the system, as had been designed. Instead, the following truck slowed to follow the cut-in vehicle at around a 3 second following distance.

The initial testing for the truck platooning system discovered critical problems that were addressed with software updates, after which relevant tests were conducted again with several minor problems. The lead tractor had radar/global positioning system (GPS) mismatch errors that needed to be addressed. Testers also found that they did not have a way to check the overall health of the truck platooning system until they were on the road attempting to engage the truck platooning mode. This led to a slowdown while the vehicle's systems were reset. The following tractor continued to switch to tractor factory ACC with truck platooning mode still engaged during cut-ins. Although this worked, the project team decided to establish an operating procedure that the following tractor would disengage in the event of a cut-in. The testing team recommended that the truck platooning system be disengaged if the tractors encountered pedestrians.

Testing revealed that truck platooning would continue even if the GPS was no longer communicating. Because of redundancy in the radar, this was not considered a problem. The testing team found that if the tractor was not started in accordance with the operating guidelines to turn the key to Accessory before turning on the engine, the truck platooning system would fail to function. The above issues were not considered serious and met the Bosch's prototype technology internal release process.

2.3 Truck Driver Training Program

Per the SMP's (Appendix A4) requirements for release of the tractors to the host fleet, TRC created a truck platooning-specific training curriculum from experience gathered during CE testing conducted at TRC's proving grounds and early public road deployments. TRC first developed on-track training followed by public road deployment training procedures using internal drivers. The host fleet drivers were then trained using on-track and selected public road deployments, followed by specialized instructions of required conditions for truck platooning, data collection goals, and pointers about potential behaviors or outcomes from public road deployment. The training objectives were to familiarize drivers with the truck platooning concept so that they would be comfortable in operating the technology on public roads. The familiarization included the drivers understanding the behavior of other vehicle drivers, including potential cut-ins and how the drivers and their tractors should react to such cut-ins. The training also provided a Driver Checklist related to the technology operation, details and need for post-trip reporting procedures, and the need to report on disengagements during a trip. The checklist and additional information about the importance of safety involving the drivers is included in Appendix A4.

The training of the EASE Logistics drivers included classroom discussion of ADAS and truck platooning background, safety, and operational conditions when truck platooning, pre-trip inspection requirements, and familiarization with the equipment on the specialized tractors in the project. On the TRC test track, the drivers were exposed to the similarities and differences between the lead and following tractor, and different scenarios for engagement and disengagement of the truck platooning technology. The drivers then participated in public road deployment training in two areas: US 33 near TRC in Marysville, Ohio and a 6-hour loop from East Liberty through Columbus, Athens, and London, Ohio.

2.4 Summary of In Revenue Service Deployment Routes

The map in Figure 6 shows the principal routes that EASE Logistics used during its 7-month deployment of the two-truck platooning-capable tractors in revenue service. The heavier lines near Columbus indicate higher volume on those roads. The road going northwest through Marysville and Bellefontaine is Ohio Route 33. The principal east-west route is I-70 with I-270 circling Columbus and I-71 going northwest. The route selection was based on the SMP's requirements, EASE Logistics' client needs, and input from EASE Logistics' drivers. EASE Logistics' experience with the truck platooning in revenue service is further described in Section 2.7.2. Note that, compared with industry practices with truck platooning, these Ohio routes were relatively short hauls for the clients involved. Shorter routes meant less platooning, which was found in some of the data discussed in Section 2.6.

FIGURE 6 – IN REVENUE SERVICE TRUCK PLATOONING DEPLOYMENT ROUTES

2.5 Truck Deployment Data Processing and Analysis

The streaming of data to Fleet Explorer and then Amazon S3 is continuous while the tractor is operating. Post processing is used to extract unusual or important events from the data. Truck platooning itself was an event from when platooning was turned on until it was turned off or disengaged. During certain circumstances, such as a truck platooning join command or a vehicle cut-in, event data can be extracted from the streamed data. An analyst can select 10 to 20 seconds of data before and after an event as a means of further explaining an event. This helps to provide visibility into system failures, disengagements, cut-ins, or other abnormal events. This event data and the accompanying full data stream were used for evaluating the performance measures.

Fleet Explorer was configured to automatically stream data into Amazon S3. It also contained built-in dashboarding, alerting, and reporting tools that were used by the project team during the deployment to monitor the system and to address system operation problems. With the dashboard, project team members could observe data in both tractors and identify interaction problems that could help with system debugging for subsequent trips. This allowed the project team and the EASE Logistics personnel to solve problems quickly and keep the tractors operating. The dashboard was used for keeping project personnel informed of truck platooning status and progress. Figure 7 presents an example of the dashboard used during the deployment.

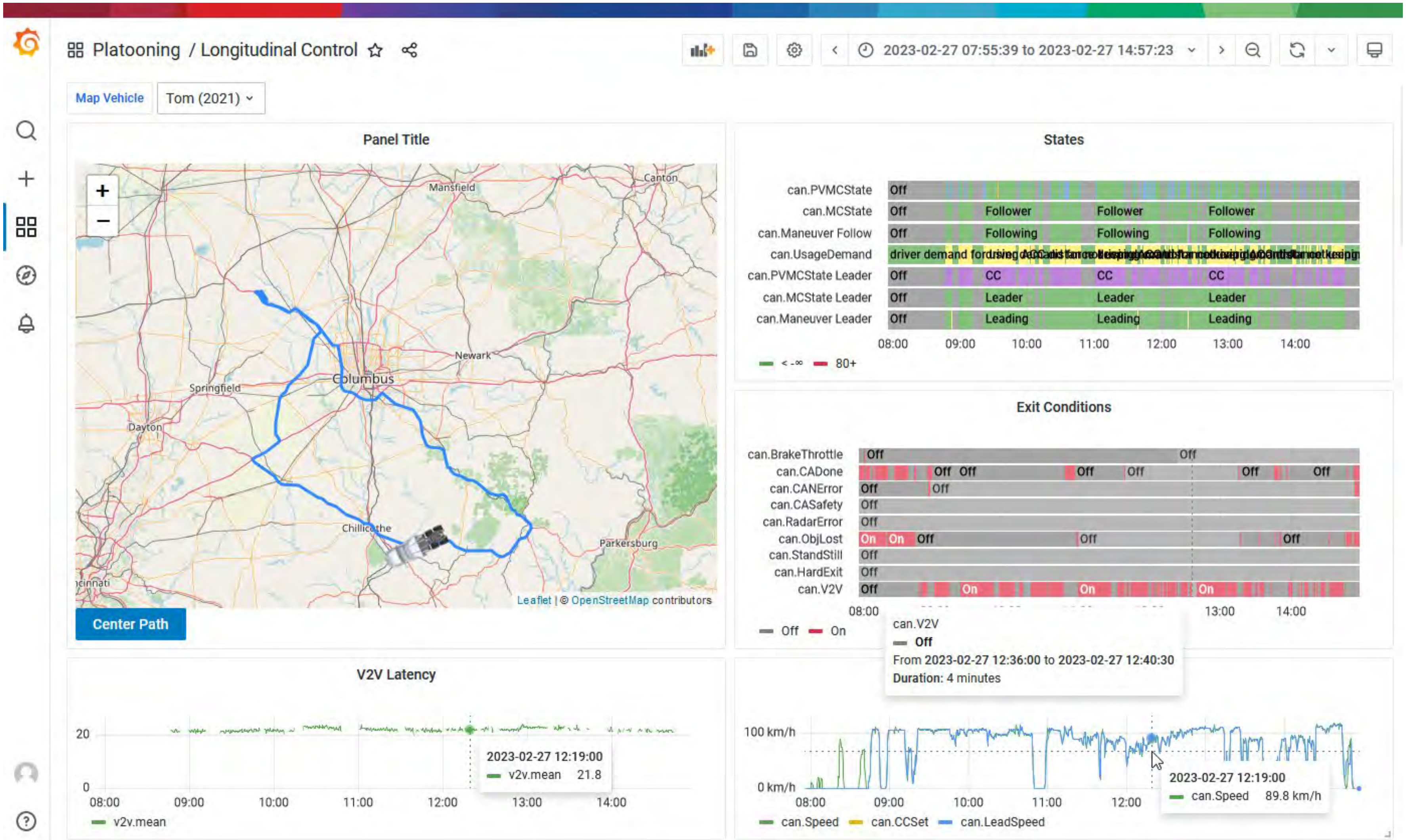

FIGURE 7 – FLEET EXPLORER DASHBOARD EXAMPLE

Video data from the on-board cameras was streamed to Amazon S3. The video data was not used by EASE Logistics or in the analyses of performance metrics. However, that timestamped video data remains available and should provide analysts and researchers a basis for further analyzing truck platooning performance, including for example video information about cut-ins or other events.

2.6 Truck Deployment Performance Measure Calculations

The project team performed an initial analysis of the data collected. The raw data behind these results is available for access in the project data repositories on ODOT's AWS environment. The discussion below provides an initial analysis of the key project metrics and provides a starting point for further analysis. The metrics used were:

- ADS Active
- Cut-Ins
- Collision Avoidance
- Gap Compliance

Trips are simply defined as any continuous data measurement event in the vehicle. There could be single or multiple trips in a day. A trip was not necessarily from the vehicle's origin to the ultimate destination.

2.6.1 Automated Driving System Active

ADS Active is defined as all times when the truck platooning system was on for more than three seconds. For the two tractors during the deployment, the time when the truck platooning system was turned on covered 11,486 miles with the total miles driven of 43,713. Thus, the system was actively platooning 26.2 percent of the time. There were 1,371 truck platooning events totaling 5,049.6 miles. Due to the prototype nature of the platoon system, it was configured to aggressively hand control back to the drivers in situations where the truck platooning might continue in operation in a fully released product. This resulted in many short truck platooning events, often just measuring in seconds. The longest truck platooning was continuously active in individual trips were in December 2023 and January 2024 at 36 minutes 26 seconds, 34 minutes 40 seconds, 33 minutes 50 seconds, and 32 minutes 39 seconds. To help understand the amount of data collected in the deployment and available for analysis, the total time during the deployments that ADS Active was on with full data collection was 120 hours 34 minutes over a 7-month period.

2.6.2 Cut-ins

The truck platooning system detected a cut-in whenever there was a mismatch between the radar location of the target vehicle and the expected position of the lead tractor based on GPS location transmission. This is usually because a vehicle has driven between the two truck platooning tractors; however, it can also happen when the lead or following tractor changes lanes without first disengaging the system. It does not necessarily mean the cut-in vehicle is too close, just that it is different from what is expected.

The total number of cut-ins during the deployment was 332, an average of one every 15.2 miles based on total miles for automated platooning miles. The radar distance to the cut-in, on average, was just under 40 meters. The time headway to the cut-in was about 1.4 seconds. The map in Figure 8 shows the locations of cut-ins during the deployment. They tended to occur in or near populated areas, with most occurring in the large urban (Columbus, Ohio) area. The green circles show the locations with fewer than ten cut-ins and the yellow circles show the locations with ten or more cut-ins. In accordance with the SMP operating procedures for the deployment, the driver always disengaged following a cut-in. While time did not permit the project team to combine video and radar data with the operational data collected, future analysis of the combined data could reveal more information.

FIGURE 8 – CUT-IN LOCATION AND FREQUENCY IN TRUCK PLATOONING DEPLOYMENT

2.6.3 Collision Avoidance

When there is either not enough distance or a large negative velocity delta between the following tractor and the radar target vehicle (this could either be the lead tractor or a cut-in vehicle), the system will enter collision avoidance mode. The event for data collection purposes was determined by looking at rapid acceleration, vehicle speed, and time headway data.

There were only six such events during the deployment, making individual event analysis straight forward.

- Two events were proper hard brake events in reaction to the forward vehicle having an abrupt deceleration event.

- Four events were erroneous detection of a passing vehicle as a "too close" target vehicle. This situation could be improved with further calibration and validation work on Bosch's prototype truck platooning system.

2.6.4 Gap Compliance

The truck platooning system's goal is to maintain a specific target time headway between the tractors. During the deployment, the target gap was usually 1.7 seconds with the largest target gap being 3.5 seconds. During dynamic driving situations, it can sometimes be difficult to maintain this gap, but it is not necessarily a safety critical situation for the gap to vary. For the project, a gap compliance event was defined as any time when the following tractor was more than 0.5 seconds closer to the lead tractor than targeted. The mean target headway time experienced during deployment was 1.84 seconds. To remove highly transient situations, cut-ins, and collision avoidance situations from the analysis, the minimum duration of a gap was set to 200 milliseconds. The total number of gap events was 51 while in truck platooning mode. While the system has a target following distance, highly dynamic driving situations can cause a differential between the target and actual following distance. To understand how frequently this situation happened, the project extracted an event whenever the actual distance was 0.5 seconds closer than the target distance. While this was not a failure of the truck platooning system, it did provide information about how frequently these situations were encountered and handled without leaving platoon operation.

2.7 Interview with EASE Logistics

Near the end of the deployment period, the project team interviewed the EASE Logistics operations team and their drivers. Highlights of this interview are as follows.

1) Reasons to participate in the truck platooning technology deployment project. EASE management had several reasons for their involvement in the deployment of two truck platooning-capable tractors hauling clients' freight including:
    a) Innovation is part of EASE Logistics' mission statement. Such a technology deployment fits that mission.
    b) EASE Logistics management is interested in exploring emerging driver assist technology to improve operations and client service. The truck platooning technology is an emerging driver assist technology.
    c) As ADAS technology grows, EASE Logistics management wanted the opportunity to better understand government regulations related to driver assist technology.
2) Truck platooning technology deployment project observations. The interview highlighted some general comments and observations about the project, including:
    a) The project rolled out as expected based on discussions with the project team and the ODOT procurement process.
    b) The truck platooning technology system had prototype issues including: 1) truck platooning system sometimes disengaged for no reason, 2) factory systems already installed on the tractors

competed and sometimes interfered with the Bosch truck platooning technology system, 3) need for an alert to the drivers if truck platooning technology was not functioning, 4) tractor radar picked up guardrails and bridge abutments on public roads, and 5) need for robust sensors and packaging of sensors for snow/ice conditions.

c) The need to be sensitive to drivers' questions about emerging vehicle automation technology and potential impact to their workplace.

3) Truck platooning technology and operations. There were several comments about the technology's impact on operations:

a) New technology has unknowns. The need to be sensitive to drivers and the entire operation is important given that a vehicle accident can have serious impact on the driver's ability to work.

b) Assuming a carrier had a fleet of truck platooning-capable tractors, truck platooning technology could be useful if a client had a "blow out of single semi-trailer cargo" situation when an additional semi-trailer may be needed for the cargo.

c) EASE Logistics experienced a rough estimate of about 10 percent fuel savings during the deployment, although no official data was collected or analyzed.

d) With a fleet of truck platooning-capable tractors, operations might require the need to modify client contracts for use of truck platooning technology.

e) There is a need for in-cab truck platooning technology standards as well as standardized driver training.

f) When implemented operationally, there would be a need to determine the best way to handle upgrades in the truck platooning technology.

g) Truck platooning deployment experience can be useful on a driver's resume.

h) The truck platooning technology is best suited for longer hauls with multiple clients. A carrier would need standardized operating regulations across states to permit longer, multi-state hauls.

i) Hours-of-service regulations would need to be adjusted to reflect second driver workload.

4) Driver reaction to truck platooning technology. Drivers shared comments about the truck platooning technology in revenue service:

a) The technology did reduce stress while driving (e.g., speed).

b) The project did use tractor chicken lights on the tractors when the tractor was in truck platooning mode to assist law enforcement (purple lights on the side of each tractor would be lit when truck platooning mode is active). In general, however, passenger vehicles were not aware of an active truck platooning mode and cut-in patterns did not change. Drivers thought tractor chicken lights can be useful but suggested the need to educate passenger vehicle drivers about their use.

c) Passenger vehicle cut-ins were more of a problem in urban areas' outer belt roads, as compared to rural divided highways and two-lane roads.

d) While operating on two lane roads in active truck platooning mode, the truck drivers would slow down to permit passing and reduce cut-ins by passenger vehicles.

e) There was a noticeable difference between driving in truck platooning mode on the test track (used for driver training) and public roads with the sensors picking up guardrails and bridge abutments.

f) From an operations perspective, there is a need to change the vehicle slowing down with the transmission and use the brakes. Bosch noted that the transmission deceleration is automatic and potentially smoother but agreed that drivers often prefer to use brakes to decelerate.

5) Client interaction and reaction to truck platooning technology. EASE Logistics had several clients agree to use the truck platooning technology:

a) EASE Logistics worked closely with their clients to gain approval to use truck platooning technology in revenue service. They had a mixed bag of clients' agreeing to participate. In general, clients had many questions. Clients did appreciate the fact that EASE Logistics drivers had truck platooning technology-related training (both classroom and test track).

b) Clients expressed interest in hosting extra truck platooning capable tractors to improve operations.

6) Driver selection and route selection process. EASE Logistics management had a process to selecting drivers for the truck platooning deployment project as well as route selection:

a) EASE Logistics looked to their more tenured drivers when evaluating operators for the project. Management spoke to all drivers about the project and the impact that this would have in the market. Not all drivers wanted to come off their normal workload or be a part of testing new technology. Once the drivers were selected, they had classroom training and rigorous hands-on training at TRC. The hands-on training was conducted on the closed test track and open road.

b) With fleet of truck platooning capable tractors, higher skilled drivers will be used in lead tractor. The truck platooning technology offers good training for less experienced drivers in the rear tractor with an opportunity to improve safety score.

c) Route selection was based on driver input, client operational needs, and client approval. Also, the project-specific deployment guidelines for truck platooning technology use on public roads were used and captured in the SMP. Note that the routes used during deployment were limited to Ohio, were relatively short, and were not multi-state as many EASE Logistics routes are.

7) Conclusions. The EASE Logistics management team had several overall comments on the truck platooning technology:

a) Participation in automation technology deployments helps industry better understand technology potential and barriers.

b) Truck platooning technology (and other driver assist automation) has a place in revenue service operations with standardized state operating regulations to permit longer multi-state hauls.

2.8 Interview with Law Enforcement

The project worked directly with the OSHP. This partnership provided both compliance with State of Ohio regulations/Executive Orders as well as access to all levels of law enforcement in regions of the state where the project had active deployments on Ohio public roads. The summary of the interview with Captain Chris Kinn (OSHP Officer) is as follows.

1) Law Enforcement Interaction. The project had several law enforcement stakeholder meetings for both the passenger vehicle and the truck platooning tractor deployments. These were separate meetings and were held in the region of the state where the deployments used Ohio public roads.
   a) These stakeholder meetings involved all levels of law enforcement in Ohio including statewide, county, and city levels.
   b) The stakeholder meeting agenda and structure were useful both to law enforcement attendees and to project personnel. The meetings involved sharing of the technology functions via a PowerPoint presentation, video of the technology in operations, and actual deployment vehicles in select meetings. The key tenant practiced at the meetings was to provide topline information but avoid too many details. From the law enforcement perspective, understanding the technology capabilities, deployment driver interactions with the technology, and the ability to ask questions will be important as the automated vehicle technology grows in use and capabilities.
   c) The combination of stakeholder meetings and periodic updates (via email) is useful to law enforcement and was conducted by the project team throughout the project.
   d) The opportunity for law enforcement to interact/drive or ride-along at a test track with the automated vehicle technology was useful. Such activities can support the OSHP's Law Enforcement Interaction Plan (LEIP) to *teach the teacher* approach to educate law enforcement about automated vehicles.
2) Partnership. The OSHP's partnership with DriveOhio/ODOT is a good example of interagency cooperation. This partnership is important as the use and complexity of automated vehicle technology grows and is deployed in a safe manner on Ohio public roads.
3) Use of Chicken Lights. The project used chicken lights located on both sides of the truck platooning-capable tractors. These lights were used while the tractor was in active truck platooning mode on public roads.
   a) Chicken lights were requested by the OSHP.
   b) The use of the chicken lights is helpful for law enforcement and helps inform issues related to driver distraction enforcement. These lights could be helpful to other highway drivers.

c) The OSHP has suggested to the American Association of Motor Vehicle Administration the use of such lights for automated vehicles operating at Level 3+.

4) Ohio Automated Vehicle Regulations Ohio's current Executive Order for Automated Vehicles outlines the current expectations and provides for state approval/permits to be provided. The requirements of the Executive Order seem to be functioning for the current technology use on Ohio public roads. For purposes of this project, the OSHP provided a memo carried in each of the project deployment vehicles which detailed the vehicle technology for use on public roads. If needed, the deployment vehicle driver could share this memo if stopped by law enforcement.

2.9 Truck Deployment Conclusions

- A large amount of data was collected and available for analysis of truck platooning operations. This includes timestamped video as well as operational data.
- The tractors performed well in revenue service and only experienced six excess braking events, which speaks well of the prototype technology in operation.
- While there were several cut-ins, there were no incidents that adversely affected the truck platooning operations.
- EASE Logistics was pleased with the performance of the technology in its regular revenue service and are interested in continuing to use the technology.
- Law enforcement was pleased with the operation of the chicken lights to show that the trucks were in truck platooning mode. Effort should be made to standardize and require such lights.
- If trucking fleets are going to use truck platooning technology across state lines, there will need to be harmonization of state regulations for long hauls involving multiple states.

3.0 Passenger Vehicle Technology Deployments

3.1 Passenger Vehicle Technology Description

For the first phase of the passenger vehicle deployments, a Fusion sedan was retrofitted with Autoware open-source ADS stack along with required hardware such as compute platform, perception sensors and drive-by-wire. After a CE test and limited deployment of the Fusion in the Marysville, Ohio area, for the second phase deployments of the project, the project team procured two Transit vans and used one OU-owned Pacifica van; all three vehicles were retrofitted with Apollo open-source ADS software and necessary hardware including perception sensors, computers, and drive-by-wire kit. After completing the configuration of the ADS passenger vehicles and completing CE testing, the project team incorporated safety-related practices outlined in the Passenger Vehicle SMP for the project (Appendix B1). Both Autoware and Apollo use HD maps for route planning as well as vehicle path following. Mandli provided the HD maps in the required formats for both Autoware and Apollo. The vehicle systems included a Global Navigation Satellite System (GNSS), a radar, video cameras, and LiDAR to maintain awareness of its own position on the road, other road users and objects, as well as roadway conditions and intersections commonly found on rural roads. Table 1 shows the capabilities of the prototype Level 3 ADS vehicles as tested and deployed and Table 2 shows the critical technologies for the passenger vehicles to achieve these capabilities.

TABLE 1 – AUTOMATED DRIVING SYSTEMS CAPABILITIES

ADS Functions	ADS Capabilities
General Driving	• Routing based on driver supplied waypoints and GNSS localization • Following waypoints, speed limit, and lane center based on HD maps • Stopping at stop sign based on HD map • Performing lane changes for waypoint following
Obstacle Avoidance	• Obstacle avoidance by speed adjustments
Navigating Intersections	• Traffic light detection • Cross traffic and oncoming traffic detection and yield • Left/right turn yield (including unprotected left)

TABLE 2 – AUTOMATED DRIVING SYSTEMS CRITICAL TECHNOLOGIES

ADS Functions	ADS Function
On-Board Computer	Level 3 ADS software stack • Localization using GNSS with real time kinematics (RTK) • Perception module using LiDAR data for object detection • Dynamic path planning module • Routing module which plans the driving route • Control module to define velocity and angle of vehicle • Live traffic operation using GNSS based localization and HD map of each route • Data collection and storage

ADS Functions	ADS Function
Sensors	Localization • GPS • Novatel OEM7 dual receiver • Inertial measurement unit (IMU) Object detection • LiDAR • Camera • Radar

The high-level architecture for the ADS platform used for the initial Fusion (using Autoware in Phase 1) CE test and Phase 1 deployment is shown in Figure 9.

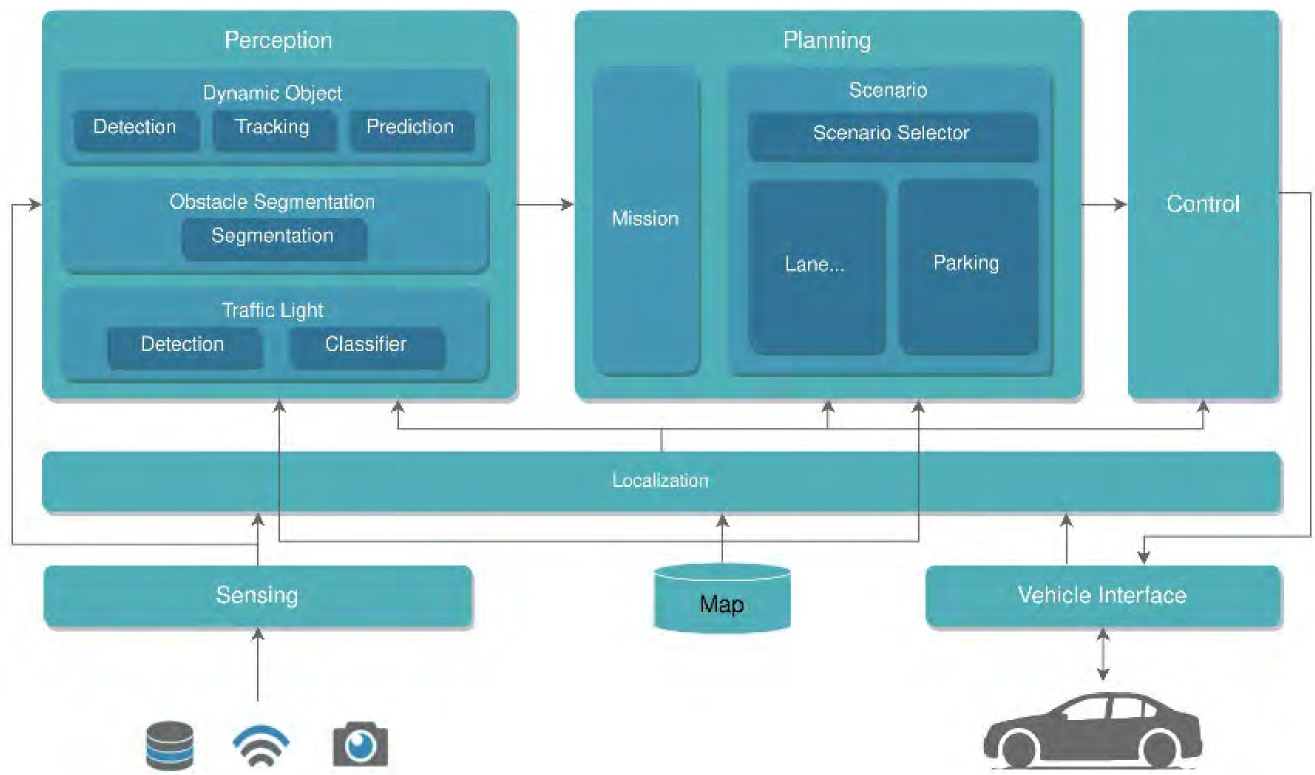

FIGURE 9 – HIGH LEVEL ARCHITECTURE FOR AUTOWARE.AI

The ADS platform used for Phase 2 deployment was Apollo 5.5, which is an open-source control stack developed by Baidu, Inc and described in more detail at https://github.com/ApolloAuto/apollo/tree/r5.5.0. It provides a set of software subsystems, such as localization, planning, perception, and control that make up the automation stack, as shown in Figure 10. The vehicles used, the two Transit vans and a Pacifica van, were outfitted with drive-by-wire kits (Hexagon PACmod for the Transits and New Eagle for the Pacifica), perception sensors, Spectra-2 computer for computation, and NovAtel GNSS aided Inertial Navigation System (GNSS/INS) for localization.

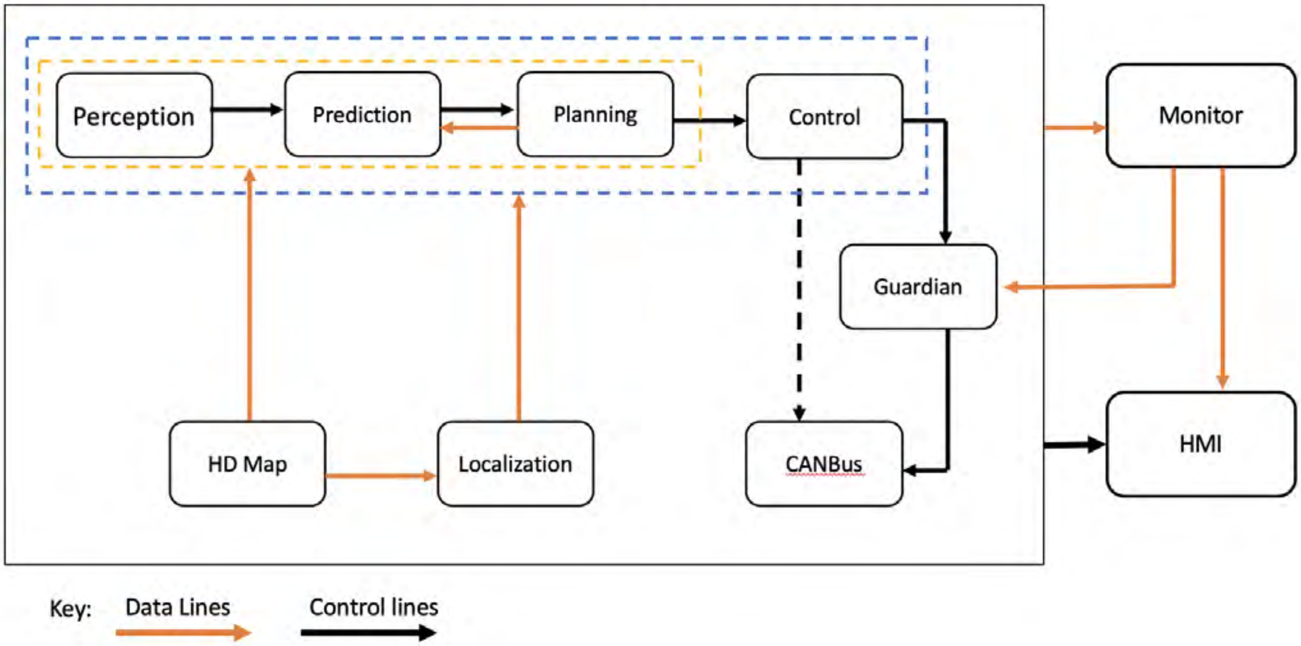

FIGURE 10 – SOFTWARE STACK DIAGRAM OF APOLLO AND THE DIFFERENT SUBSYSTEMS
Source: developer.apollo.auto

The Apollo control software uses DreamView as HMI for control over autonomy, selecting a route (start and end), and live visualization of different signals. Figure 11 shows a view of this HMI visualizer.

Additional details about the Transit vans using Apollo software are contained in Appendix B2.

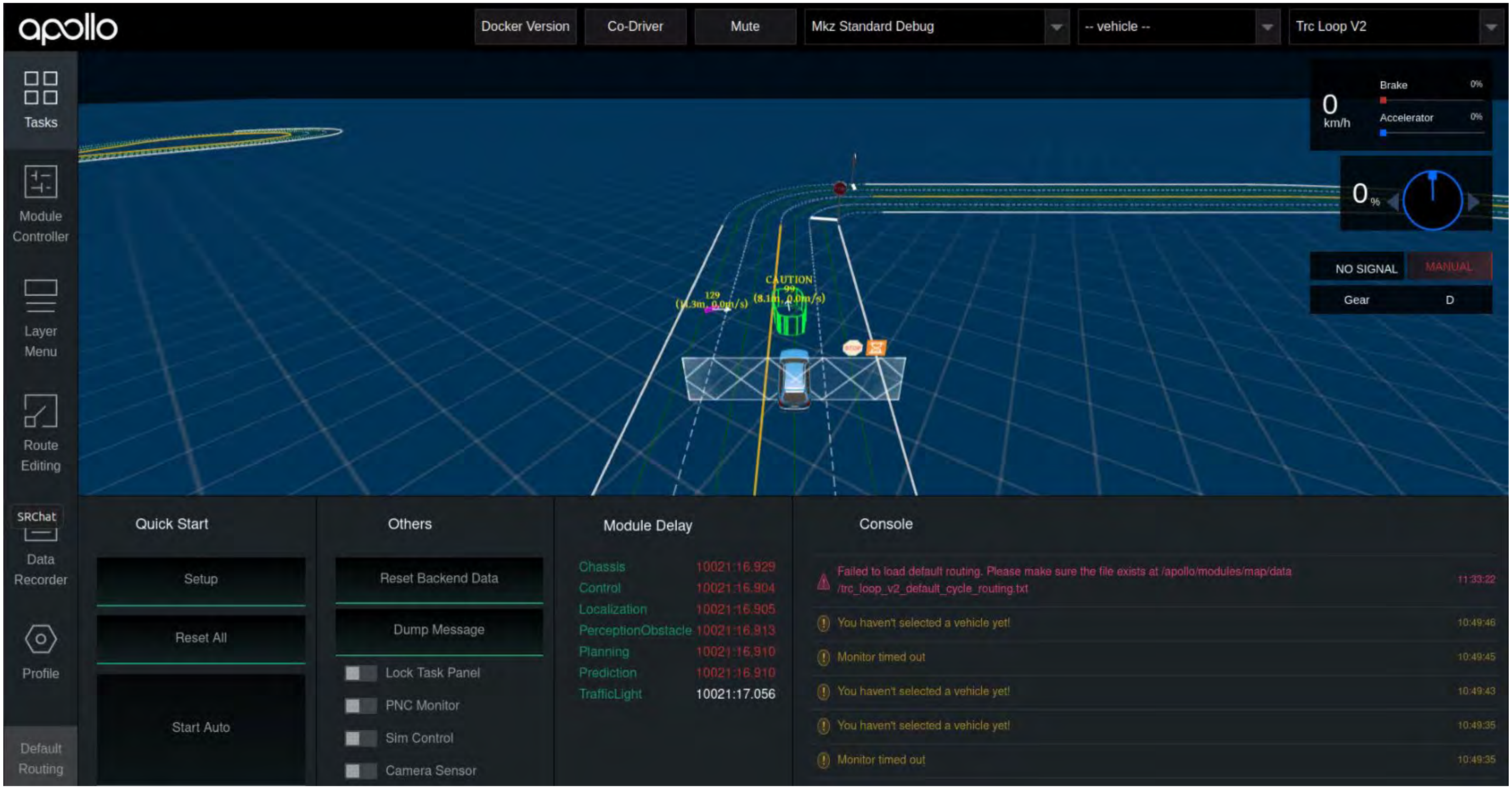

FIGURE 11 – VIEW OF APOLLO'S DREAMVIEW VISUALIZER WITH OBSTACLE DETECTION

3.2 Automated Driving Systems Data Collection Modes

The vehicles with their sensors, on-board computer, and automation software stack collected data for analysis purposes to show how the vehicle performed on rural public roads. After the initial CE test of the Fusion (Phase 1), the team decided to have three data collection modes to maximize the data being collected. These were called buckets 1, 2, and 3:

- Bucket 1 manual mode. In manual mode, the automation is turned off, but localization and perception software are running which will show vehicle path and location in the data.
- Bucket 2 shadow mode. In shadow mode, the automation software plans the route. The vehicle is not engaged in automated mode, but the data from the planning and control module is also available besides the data collected in manual mode.
- Bucket 3 automated mode. In automated mode, the ADS software is fully engaged, and the safety driver takes over as needed. In this mode the control module of the ADS is controlling the steering and brake and gas pedals using the drive-by-wire module and all that data is collected.

In each mode, data is stored on the on-board computer and off-loaded after the trip is completed.

3.3 Overview of Passenger Vehicle Tests

CE testing was conducted by the project team for each of the vehicle types (Fusion, Transit, and Pacifica). The objective in each test was to expose the ADS-equipped vehicle to progressively complex situations, test the ADS's response, collect operations data, and inform the safety driver teams of expected system behavior. Because only one vehicle was available for the first CE test (Phase 1), the project team decided to have a limited deployment in the Marysville, Ohio area while waiting for additional vehicles to be outfitted and tested.

3.3.1 Controlled Environment Testing of Ford Fusion with Autoware

A detailed CE Test Report for the Fusion in Phase 1 was completed at the TRC Inc. SMARTCenter in East Liberty, Ohio in early 2022 (Appendix B3). A high-level summary follows.

The TRC team that conducted the Fusion CE test observed the limitations of ADS software and laid the groundwork for later deployments. They conducted two rounds of tests. The first consisted of basic systems tests intended to test functionality and performance of ADS subsystems over a broad set of features and the second round of testing exposed the ADS to situations with increased complexity within a chosen subset of functionality. Functions tested included control, localization, object perception, and route planning. The first tests demonstrated various deficiencies in the Autoware software that had to be corrected prior to any public road deployments or that limited the vehicle's operation. The tests demonstrated that nearly all ADS components could be non-operational, and the driver could still engage the ADS. The TRC team added custom software into the ADS stack that would ensure basic safety checks were performed prior to ADS engagement and throughout ADS operation to ensure that all sensors were operational prior to a vehicle engagement. The first round of testing informed the finalization of tests completed for Round 2 of testing. In

Round 2, the tests were designed to examine navigating the vehicle on a multi-user roadway and understanding interactions with other vehicles or road users at intersections.

Some of the key outcomes or observations from this CE test included limited object detection range of about 131 feet with vehicle speed greater than 35 miles per hour (mph), which means a vehicle at that speed would not be able to stop within hitting an object. The smaller range of object detection resulted into a speed limitation of 35 mph for safe operation on public roads. Traffic light detection was very unreliable. The positioning of the single LiDAR on the vehicle made it impossible for the vehicle to detect small objects such as child pedestrians. While the vehicle was able to stop at some intersections, it had difficulty at four way stops and with some right turns. In those cases, the driver disengaged to handle the intersection appropriately.

3.3.2 Deployment 1 (Phase 1) in Marysville Area

After the conclusion of CE testing, the project coordinated with local officials and law enforcement and obtained state approval for a limited deployment on five short routes in the Marysville, Ohio area. The project acquired HD maps from Mandli for each of the routes. Those routes are listed in Table 3.

TABLE 3 – DEPLOYMENT 1 ROUTES

S No.	Route Name	Length (miles)
1	Bellefontaine	3.3
2	Marysville	2.5
3	Renner	8.8
4	North High	1.9
5	Avery Road	3.8

Based on the limitations in the software found during the CE test, the TRC team planned a series of deployment runs on each of the routes. Initially, they used manual mode, but during the deployments more runs were completed in automated mode. Runs were completed only in good weather and, if there was an anomaly on the route, (e.g., construction zone, emergency vehicles, etc.), the safety driver was instructed to disengage the ADS and re-engage only after clearing the anomaly. The ADS was also disengaged in the presence of any other vehicles or vulnerable road users (VRU). The deployment found errors in detection of traffic lights and the project team increased the size of the rectangular section of the image where the camera image is segmented, which was of some help.

Nevertheless, the vehicle could run in automated mode more than had been planned or expected. Deployment 1 involved 277 total runs on 5 routes covering 1,233.5 miles, with 9.8 terabytes of data collected. Figure 12 and Table 4 show the results of the deployments on the five routes in terms of data collected by bucket type and mileage. Figure 13 shows the map of the Renner route on which more miles were driven than the others. Maps of the other routes are included in Appendix B4.

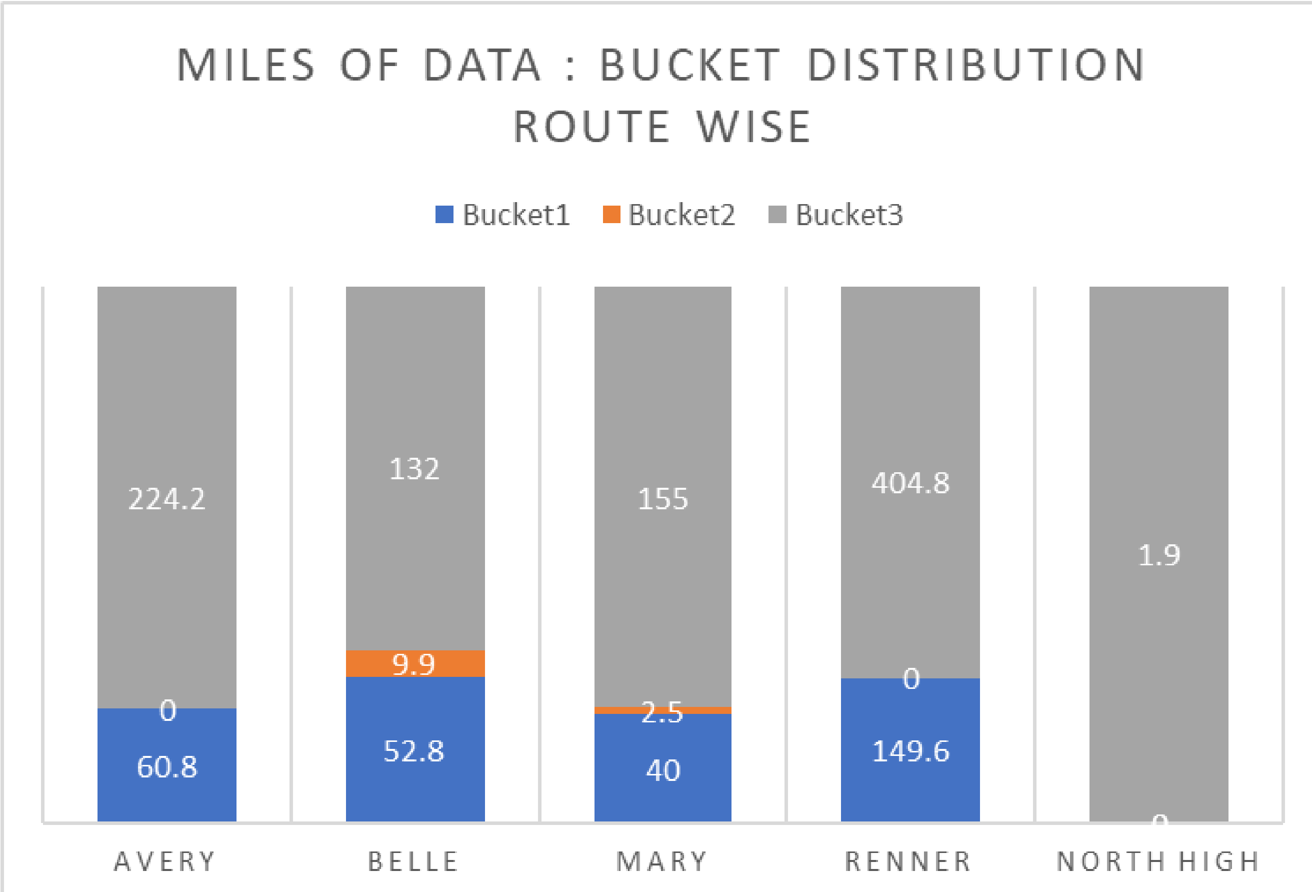

FIGURE 12 – ROUTE WISE BUCKET MILES

TABLE 4 – ROUTE WISE BUCKET MILES AND PERCENTAGE OF ROUTE MILEAGE

Bucket	Avery		Belle		Mary		Renner		North High	
	Miles	%	Miles	%	Miles	%	Miles	%	Miles	%
1 – Manual Mode	224.2	79%	132.0	68%	33%	74%	404.8	73%	1.9	100%
2 – Shadow Mode	0.0	0%	9.9	5%	29%	1%	0.0	0%	0.0	0%
3 – Automatic Mode	60.8	21%	52.8	27%	20%	25%	149.6	27%	0.0	0%

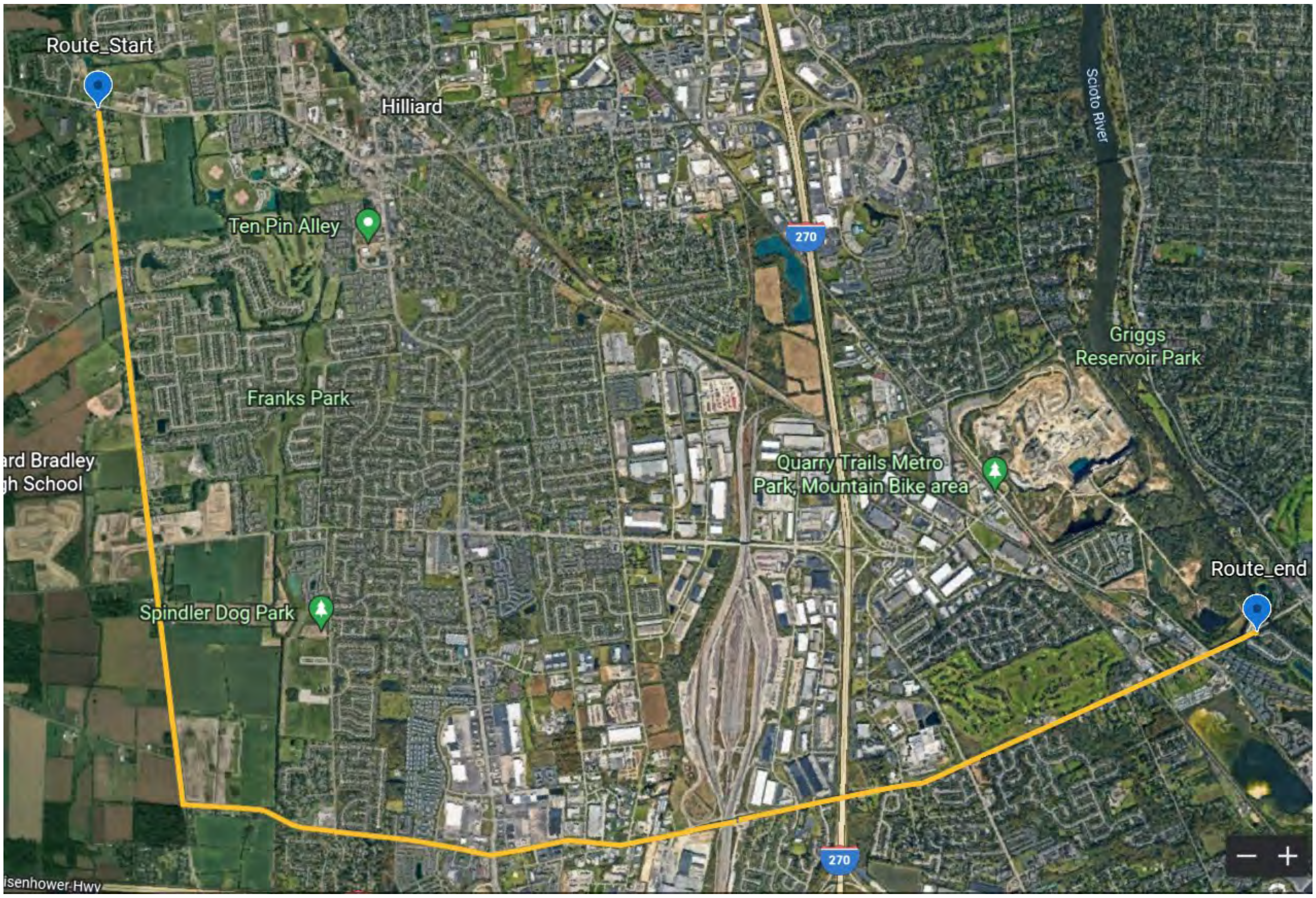

FIGURE 13 – RENNER DEPLOYMENT ROUTE

3.3.3 Selection of Apollo for Additional Automated Vehicles

Following the Fusion Deployment (Phase 1) in Marysville, Ohio, the project team examined other possible ADS software stacks, comparing the characteristics of ADS automation capabilities of Autoware with Apollo. The team prepared a Trade Study analysis that established high-medium-low importance to each capability and then noted whether Autoware and Apollo had the capability. Using a weighted score based on importance, the team found that Apollo scored better than Autoware. Key differences were:

- Ability to route and plan at speeds greater than 35 mph
- Operating at speeds greater than 35 mph
- Detecting edge of roadway and pavement markings
- Detecting signs
- Performing cooperative lane change
- Having a better HMI

Based on the analysis, the project team selected the Apollo software stack and implemented it on two newly acquired Transit vans and an existing Pacifica van. Apollo software was used in Phase 2 of the project.

3.3.4 Controlled Environment Test Results for Apollo

The two Transit vans and the Pacifica van now operating with Apollo were then subject to CE testing, the Transits at the TRC Inc.'s SMARTCenter (Appendix B5) and the Pacifica at OU (Appendix B6)[1].

The CE tests evaluated the vehicle ADS capabilities to follow prescribed path, recognize and obey stop signs and traffic signals, engage into automated mode when driving at speed, navigate in the presence of other road users, and perform lane changes. HD maps for TRC Inc.'s SMARTCenter and for a 0.5-mile private road loop at the edge of the OU campus in Athens, Ohio were acquired from Mandli. The object detection capability was tested on straight and curved road geometries. The ADS capability to navigate at intersections with other road users present was tested. More specifically, scenarios for unprotected left turns, turn only lanes, yield for oncoming traffic, and yield for pedestrians at stop signs were tested.

While the CE testing was successful enough to allow the Transits and the Pacifica to enter Deployment 2 (Phase 2) on the three project-designated routes in the Athens, Ohio area, some issues were identified in testing that needed to be worked around for successful deployment.

Object Detection

During CE testing, it was noticed that the Apollo system was not able to avoid stopped obstacles when driving above 35 mph. Tests with different target objects, distance, and speed showed that the Apollo system has object detection range of approximately 50 meters for standard sized cars and adult pedestrians and only about 25 meters for large objects such as truck trailers and small objects such as child pedestrians.

Traffic Light Detection

The project team observed that the Apollo traffic light detection system functions but is not reliable. The uncertainty in the detection resulted in the TRC team designing and implementing a dashboard indicator light for the Transits to show the traffic light color the Apollo is perceiving. OU used DreamView to observe traffic signals.

Lane Keeping on Curved Roads

The TRC team experienced discomfort while driving on curved sections. The system was able to keep the vehicle inside the lane line markings, but it did not slow down enough to ensure comfortable lateral acceleration and lateral errors. The driver and the operator "felt like the vehicle was going to leave the road and would have slowed down if manually driving." The OU driver team experienced this later during deployment and obtained maps from Mandli with lower speeds in some areas to reduce lateral accelerations.

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[1] The Transits CE test was also described in an SAE World Congress 2024 paper titled "Closed Track Testing to Assess Prototype Level 3 Autonomous Vehicles Readiness for Restricted Public Road Deployment."

Lane Changing Issue

The project team ran tests involving lane changes and found that if another vehicle was present, the ADS vehicle drifted toward the other vehicle. The OU team found that the Pacifica thought a bus was in its lane, so the Pacifica stopped. There were also GPS issues at the OU test route. The TRC team observed possible conflicting decisions by the ADS between obstacle avoidance and planned route.

Sudden Large Steering Torque when Engaging at Speed

The TRC team tested the system's ability to engage or re-engage into automated mode when manually driving at higher speeds. In this test, a routing request requiring lane change was sent. The vehicle was driven manually for some distance in the same lane and then, while driving, the system was engaged into automated mode. It was observed that the system replanned the route and made a sudden lane change with unacceptable steering rate.

Conclusion

Despite these issues, the project team thought the Apollo software performed better than Autoware and decided to proceed with HD map verification and deployment for Apollo on the selected three project designated routes.

3.4 Three Deployment Routes Near Athens, Ohio

Following the CE tests, the three vehicles were deployed to three carefully selected routes in the Athens, Ohio area. The routes were chosen to encompass typical North American rural driving environments. These routes included different types of intersections (e.g., roundabout, stop sign, and signalized). The rural environment had a wide variety of road users including sedan cars, trucks, freight trucks, tractors, adult pedestrians, child pedestrians, and animals like deer.

The three routes selected by the project team were given the colors Blue, Red, and Green. They are shown on the map in Figure 14 and include urban and suburban areas in the Athens, Ohio area along with state and county roadways around and to the west of Athens. The Green Route is in Vinton County at the far lower left of the map. Each route is described in more detail below.

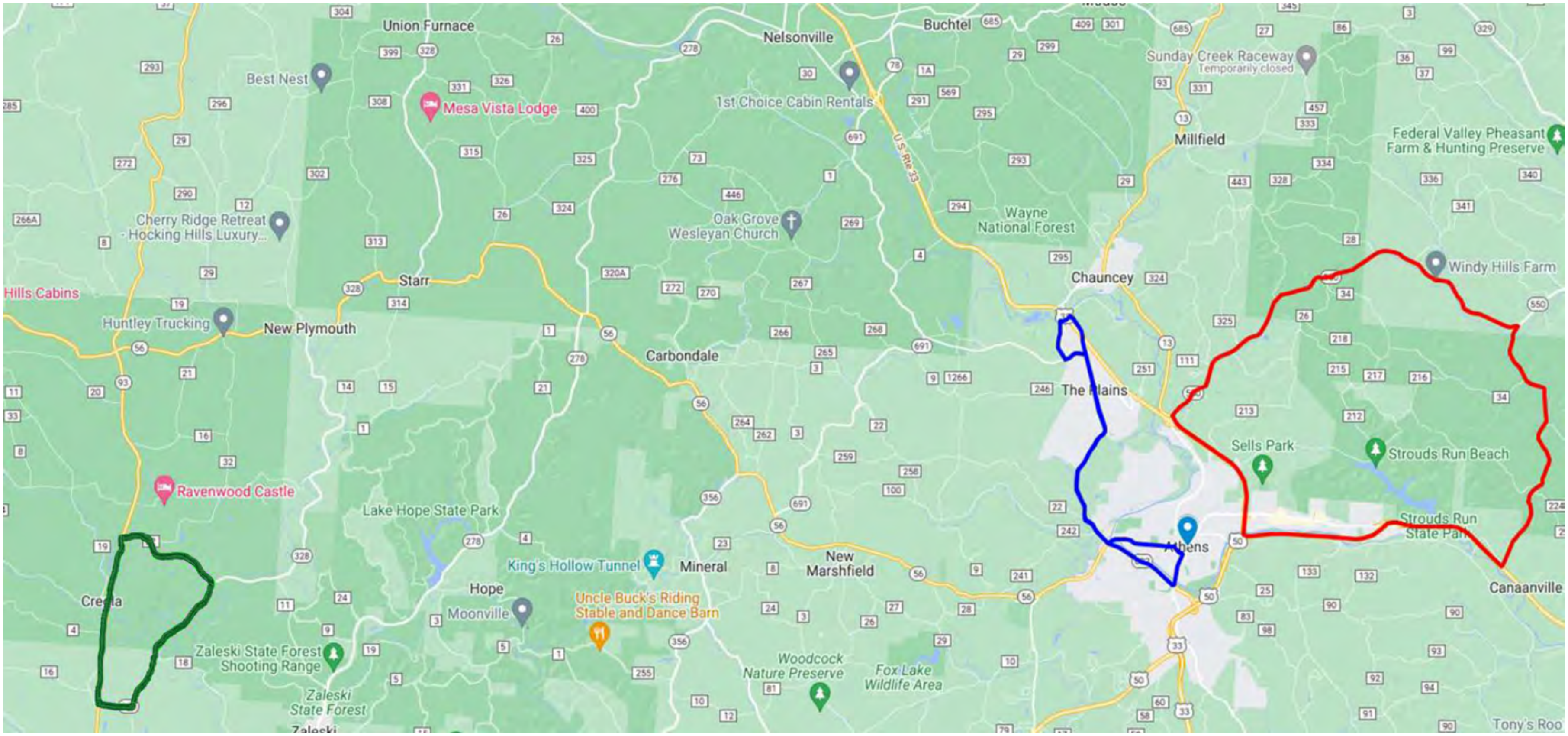

FIGURE 14 – SOUTHEAST OHIO DEPLOYMENT ROUTES

3.4.1 Blue Route

Figure 15 presents a map of the Blue Route, which begins and ends at the intersection between West Union Street and South Plains Road in Athens near the ODOT District 10 facility. The route is 13.0 miles long round-trip with a northern and southern loop connected by a straight segment that would be traversed twice in opposite directions. The responsibility for the roads on the route is divided among state, county, and township, but is largely composed of state roads. The route is designed to be traversed to only have one left turn movement at a signalized intersection with a dedicated left-turn lane and left-turn phase at North Plains Road and Poston Road. The key features of the Blue Route include:

- Two roundabouts
- Signalized intersections
- Narrow roads without lane markings

The vehicle is intended to travel straight through a multi-lane roundabout without a lane change. Narrow roadways make up parts of the route, with no delineated shoulder in parts of the northern loop. The Blue Route passes through semi-urban and rural areas with tree cover and some potential for multi-path interference.

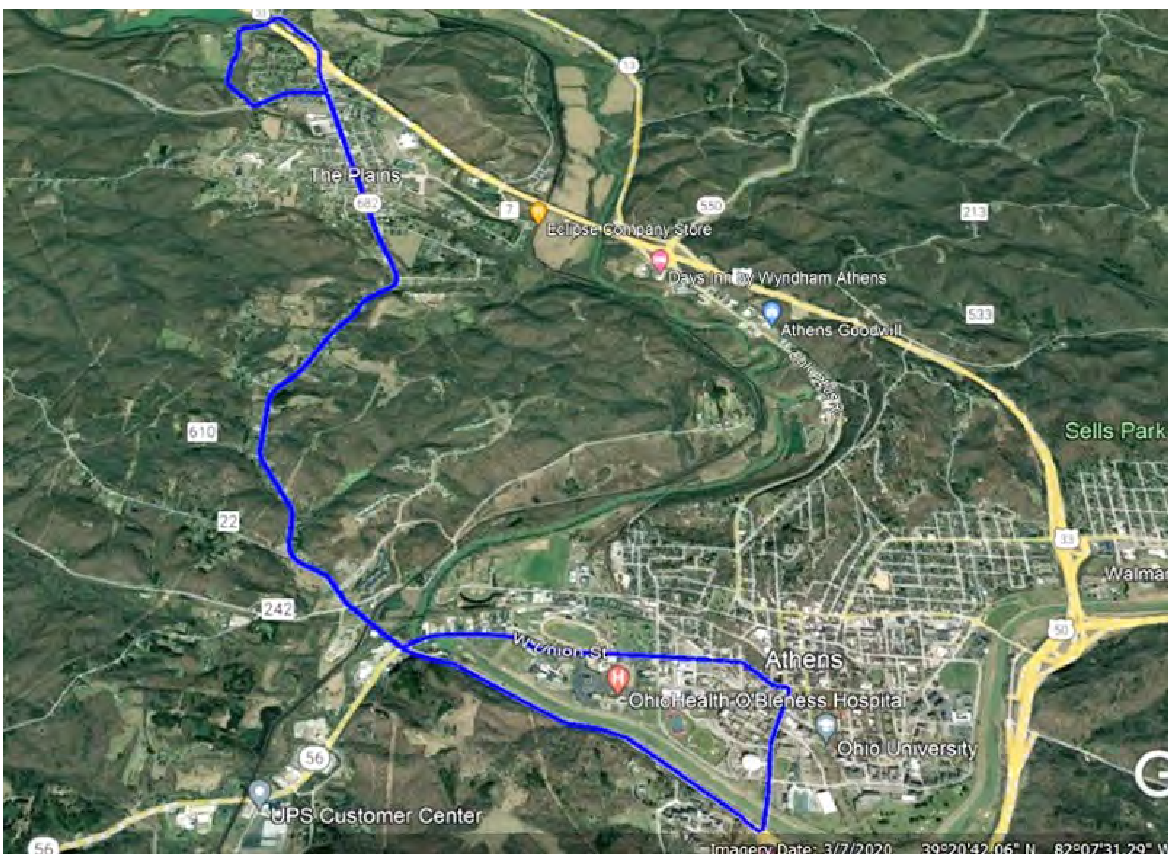

FIGURE 15 – BLUE ROUTE

3.4.2 Red Route

The Red Route is a loop that begins and ends on State Route (SR) 550. At 20.7 miles long, it is the longest ADS deployment route. The responsibility for the roads on the route is with the state. If driven clockwise, the route consists entirely of right turns. The roads have various speed limits; the highest being 60 mph on US 32.

The key features of the Red Route include:

- Signalized intersections
- Yield and Stop signs
- Two-lane undivided road with no shoulder space
- Highway lane merge

Narrow roadways make up parts of the route in SR 550 and SR 690. As the vehicle leaves US 32 and enters the US 33/US 50 freeway, it will need to make a lane change to the middle lane, as the right lane becomes a lane for exit 196. Figure 16 presents a map of the Red Route that shows some of the natural features that may challenge GPS and other system operations. The Red Route passes through rural and hilly areas with a lot of tree cover.

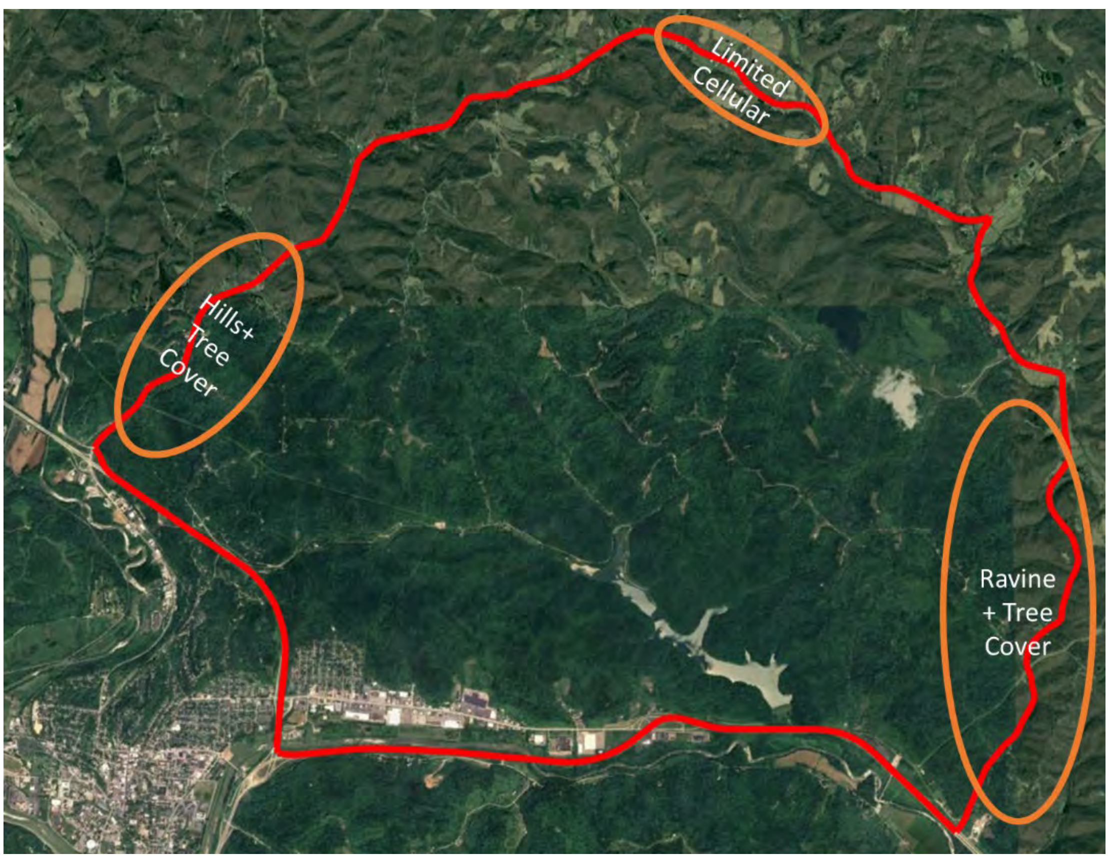

FIGURE 16 – RED ROUTE

3.4.3 Green Route

The Green Route begins and ends at the Vinton County Airport and incorporates Vinton County into the deployment. At 8.42 miles long, it is the shortest deployment route for passenger vehicle automation. The responsibility for the roads on the route is split between state and county. If driven clockwise, the route consists of entirely right turns. All roads are posted at 55 mph, or not posted at all implying a 55-mph speed limit. The key features of the Green Route include:

- All right turns
- Passing zone

The roads in the route have adequate pavement markings, indicating a normal lane width to transverse. Figure 17 is a map of the Green Route developed in Google Earth to diagram the profile of the route. The Green Route is in Vinton County along rural roads.

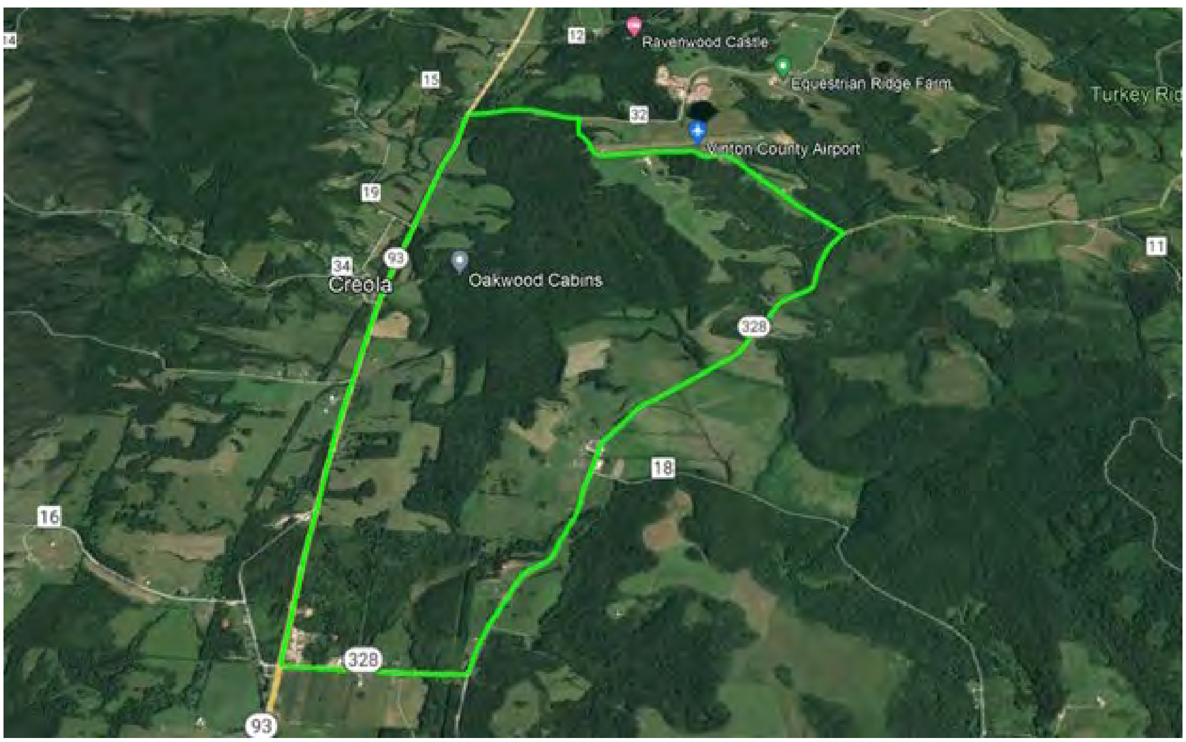

FIGURE 17– GREEN ROUTE

3.5 High-Definition Maps and Verification Process

HD lane vector maps for navigation contain information about the road network with centimeter level accuracy. These maps include precise locations of the lane lines, stop-bar locations for stop signs and stop lights, traffic light locations on the map, speed limits, and all possible turns at intersections. HD maps are crucial for the autonomous driving systems of both Apollo and Autoware. These roadway details facilitate path planning in the software stack. The automation stack uses GNSS to locate the vehicle's position in reference to the lane lines in these maps. The project received HD maps from Mandli in a form that could be loaded in these systems.

The generation of HD maps followed a comprehensive process as shown in Figure 18. The first step is the calibration of sensors including GPS, IMU, cameras, and LiDAR systems. GPS provides global localization, IMUs give vehicle dynamics and orientation, cameras capture visual features, and LiDAR sensors generate detailed three-dimensional (3D) point clouds of the surroundings. Calibration is crucial as it aligns and synchronizes data from different sources, ensuring accuracy in the representation of the vehicle's surroundings.

Following calibration, feature extraction of the sensor data takes place. During this phase, specific characteristics such as lane markings and traffic signs are identified and extracted from the sensor data. Once features are extracted, data association is performed. This involves linking the extracted features with corresponding 3D elements within the point cloud map data. The point cloud map is a high-resolution 3D representation of the environment constructed from the LiDAR data. The final step is the actual generation of the map, which incorporates all the associated data and the detailed point cloud map to create a vector map that accurately represents the drivable lanes and their relations.

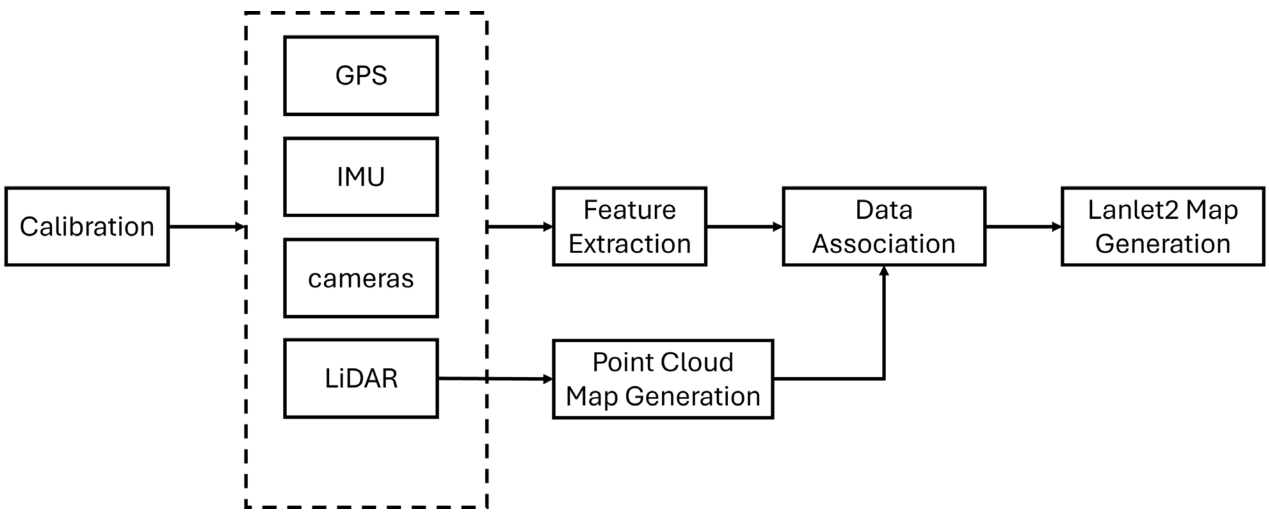

FIGURE 18 – HIGH-DEFINITION MAP GENERATION

For Deployment 1 (Phase 1), Autoware-compatible maps were procured from Mandli for the five routes in the Marysville, Ohio area. For Deployment 2 (Phase 2), Apollo-compatible maps were procured from Mandli for TRC Inc.'s SMARTCenter, the private road loop on OU campus, and the three project designated deployment routes in or near Athens.

For all routes, maps were verified to ensure their correctness for lane line positions in global coordinates, speed limits, and stop-bar locations. Apollo's Dreamview shows a live view of vehicle position and speed limits while driving on the route. The project team adopted a two-step approach for map validation. In the first step, safety drivers drove the vehicle in shadow mode along the route while manually keeping the vehicle centered in the lane. During this driving, an ADS operator monitored the Dreamview interface taking notes of inconsistencies in the map including speed limits, lane line departures, and traffic light or stop sign detections. Localization data was also recorded during the verification drive.

Plotting the localization data during manual driving on the HD maps and close examination of these plots revealed inconsistencies between actual and map speed limits or lane locations. An example of Red Route speed limit discrepancies is shown in Figure 19 and detailed in Table 5. Some basic map errors were also identified during the manual drive; for example, a stop sign intersection was incorrectly marked as a signalized intersection. Similarly, a railway crossing was marked as railway crossing in the map although the ADS platforms were incapable of navigating around railway crossings. Hence, it was changed to a stop sign intersection for better operation and to give time to the drivers to disengage if railway crossing gate is down.

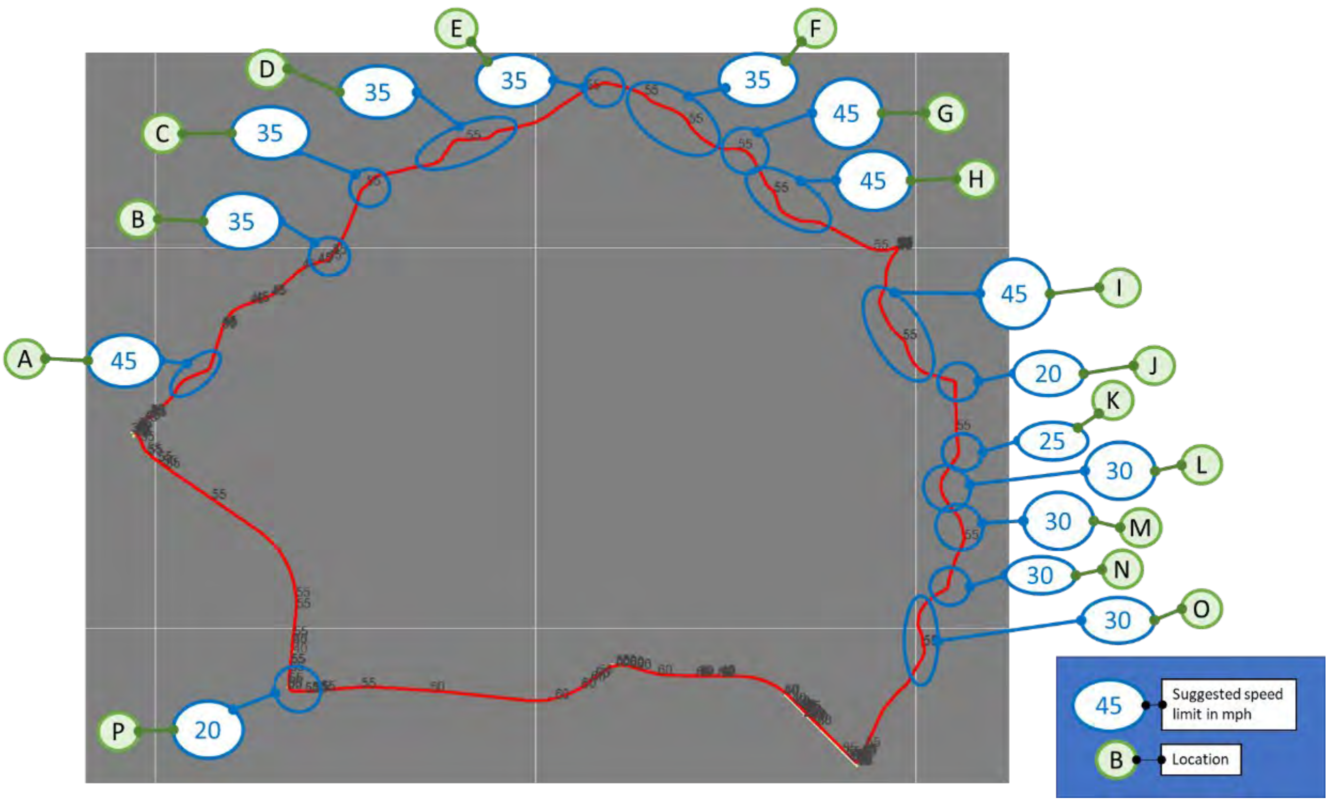

FIGURE 19 – RED ROUTE SPEED LIMIT DISCREPANCIES

TABLE 5 – RED ROUTE SPEED LIMIT DISCREPANCIES

Location	Suggested Speed Limit in mph
A	45
B	35
C	35

After the speed limits, lane locations, and intersection types were verified and corrected by manual driving, the system was engaged in automated mode on these routes. The main goal of this map verification phase was to identify places on the route where the system is not able to operate properly. For example, on a small segment on the Green Route, due to a steep up-hill road and multiple connecting driveways and visibility issues, the speed limit was reduced from 55 mph to 45 mph for safety purposes. Furthermore, at some intersections, the automation system failed to turn on the turn signal because the map did not have splitting road segments at those intersections. Related to the speed limit issue, OU requested a second HD map of the Red Route because the vehicle operators were not comfortable driving at the posted speed limit included in the original map.

3.6 Deployment Data Upload and Conversion

Table 6 shows two primary types of data collected by the vehicle: operational data about vehicle performance as it drives and data in the environment surrounding the vehicle obtained by multiple video cameras and LiDAR. The operational data identifies whether the ADS functionality is operational and detects handoffs between the driver and the ADS. The video and LiDAR show adjacent vehicles and their motion, as well as roadway lanes, obstacles, or other roadside objects that the ADS needs to detect to perform the correct L3 driving functions.

TABLE 6 – DATA TYPES FROM PASSENGER VEHICLES

Data Type	Data Element Description	Type/Scale	Collection Method	Frequency
Vehicle Operational Data	ADS/ADAS control signals data from on-board systems including GNSS: • Vehicle position in 3D and orientation globally • Vehicle speed - linear and angular velocities • Vehicle acceleration • Steering wheel inputs • Accelerator/brake pedal position inputs • Identified points of the transition of responsibility of the driving task between the ADAS/ADS and the supervising human driver. • System settings (e.g., ADS mode).	Numerical and positional data	Operational sampled data from GNSS, drive-by-wire system, and on-board computer	up to 100 Hz
Driving Environment	Principal other vehicle(s) position	LiDAR data	LiDAR	10 Hz
	Traffic light detection and status	Video data	Video camera	15-30Hz
	• Principal other vehicle(s) speed. • Principal other vehicle(s) acceleration. • Leading, following, and other POV IDs	• Radar • LiDAR	• Radar • LiDAR	10 Hz
	• Relative speed (compared to subject/instrumented vehicle). • Relative spacing (compared to subject/instrumented vehicle).	LiDAR data (.pcd)	LiDAR	10 Hz

Autoware data and the use of Robot Operating System (ROS) and rosbags for data storage are described in the Fusion CE Test Report and Deployment 1 Report (Phase 1). Apollo, as used in the Transits and Pacifica for

Deployment 2, uses protobuf as a language for communication between modules and data storage. The files generated from Apollo that store data are called cyberbag files which can have data extracted using a custom developed Python program and the data can be viewed in Dreamview (Phase 2).

Cyberbag data is stored in topics with a unique time stamp and set of data. Each individual sensor's raw data utilized one topic and the combined and corrected data (for the sensor's location relative to the vehicle reference point) is a separate topic. Most internal systems communications and external commands to the vehicles were captured in the cyberbags. There are 38 topics that Apollo used in the software stack and these topics represent the operational and environmental data collected by the vehicle. Appendices B1 and B8 provide the list and definitions of these topics.

Two key topics are particularly interesting and useful in analyzing the Apollo data. These are 'apollo/canbus/chassis' which records much of the operational data about the vehicle's real time performance, and 'apollo/sensor/gnss/best_pose' which provides location and other information needed for operation in automated mode. The fields within each topic and the definitions are included in Appendix B7.

As shown in Figure 20, the data from the passenger vehicle was collected in an on-board computer and stored on a removable solid-state drive. The cyberbag data was uploaded from the vehicle to AWS S3 after it had completed its daily operation or by swapping out hard drives. The upload included metadata related to each collection including weather and driving comments. The project team wrote scripts to upload and store the data in Amazon S3. They also wrote scripts to convert uploaded cyberbag files into an indexed format in Amazon DynamoDB for the purpose of queries and analysis. The data included LiDAR data, as well as operational vehicle data. The LiDAR and video data were converted to non-indexed data with appropriate time stamps. The operational data was inserted into an Amazon DynamoDB table using a custom-made Python program. All deployment data collected by the two Transits and the Pacifica have been converted and are stored on Amazon S3 and Amazon DynamoDB. To facilitate the analysis, metadata is included as appropriate and allows analysts to query the data to provide visualizations.

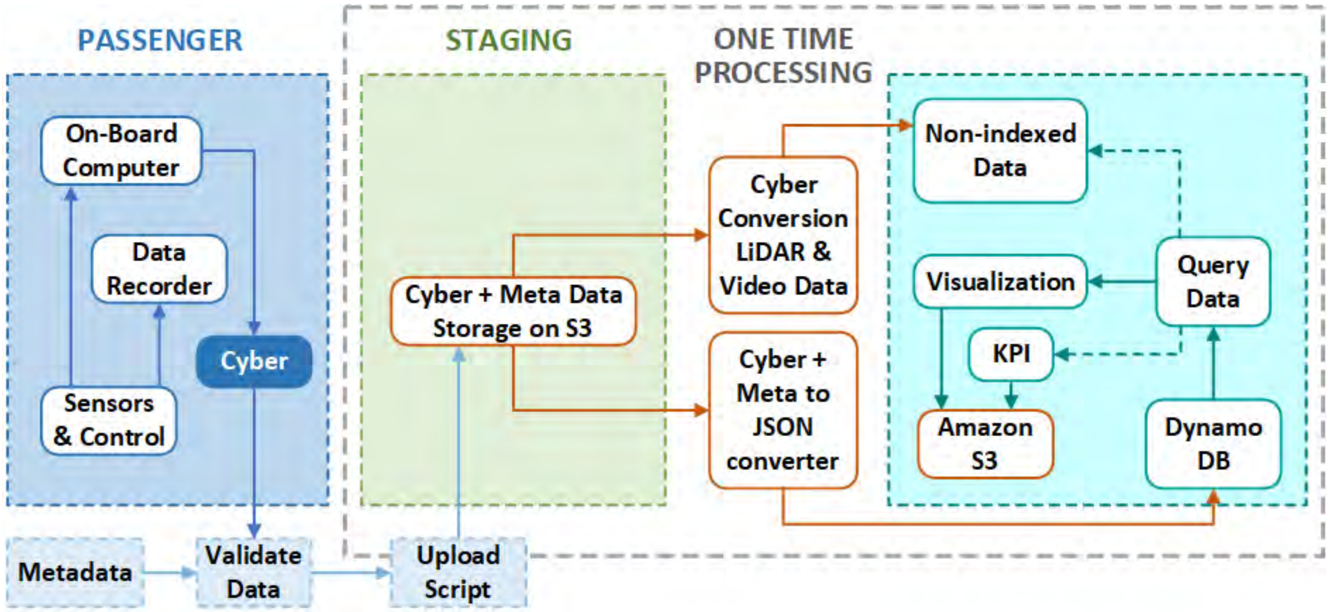

FIGURE 20 – DATA UPLOADING AND CONVERSION PROCESS

In Amazon DynamoDB, the data is organized by run with each run (or experiment) having a unique GroupMetadataID. Each cyber data file has a unique entry to the metadata table in DynamoDB with a common GroupMetadataID that is unique to each data collection instance. The data was structured in two large tables: ADS Passenger and ADS Passenger/meta. The Passenger table contains the specific cyber messages except LiDAR and camera images collected during a run while the Passenger/meta table contains identifying data for a run including:

- Time
- Experiment ID
- Vehicle ID
- Driver
- GroupMetadataID
- Map

The GroupMetadataID is the key between the two tables that enables them to be quickly combined with appropriate timestamps and identifiers for each run. Running scripts that combine these tables allows analysts to perform queries of the data. Such query scripts were developed during the latter stages of the project by OU and YSU. Their open-source work is available on GitHub at https://github.com/DriveOhioADS/ADSRawDataConversion.

3.7 Overall Deployment Results

Overall, the three vehicles in Deployment 2 near Athens covered 3,822 miles across the three routes, providing a substantial dataset for analysis. The data collection system keeps track of the driving mode, recording manual, automated, and emergency state. Emergency state is the transition between automated and manual, which is usually short. For simplicity of the analysis, the project team decided to combine emergency and manual modes and use manual as the name. The numbers and graphs that follow use "manual" to represent driving time and distance in the combined manual and emergency modes. There was a significant amount of driving in both manual (1,210 miles) and automated modes (2,611 miles), with automated mode accounting for a larger share of the total miles driven (68.3%). There were 331 total runs by the three vehicles of which 249 runs were in automated mode at least some of the time, and 82 in manual mode only. The manual runs were in shadow mode. Those runs were not intended to be in automated mode and usually involved map verification or safety concerns with the ADS system that needed troubleshooting and sometimes system upgrades or corrections before driving in automated mode again. Driving in shadow mode allowed data to be collected for analysis even though it did not involve automated control of the vehicle and thus did not have disengagements. The number of runs in the Deployment 2 was similar amongst the three routes with slightly more on the Blue Route (121 runs) compared with the Red Route (101 runs) and the Green Route (109 runs). Route-specific manual and automated miles are described below:

- Blue Route. The automated mode covered more miles (995 miles) compared to manual mode (470 miles), or 67.9% automated. There were disengagements and more manual driving in the urban parts of the route where traffic and pedestrian volumes were larger.
- Red Route. Although this route had curvy and hilly terrain and some areas where GNSS and cell service were lost, the miles driven in automated mode were more than twice the manual mileage (504 manual miles vs. 1,032 automated miles), or 67.2% automated. The rural features of the route necessitated disengagements and manual driving in certain areas.
- Green Route. This route showed the highest proportion of miles driven in automated mode (585 miles) compared to manual mode (237 miles) or 71.2%. The route is the most rural with fewer intersections. The traffic volume is less, although often the other traffic travels at speeds higher than the speed limit. The project drivers were most comfortable with sustained automated operation on this route.

A diagram of the mileage on three routes driven in both automated mode and manual mode is shown in Figure 21. Figure 22 shows the runs per vehicle for the three routes. Red is the Pacifica, Orange is Transit Van1, and Blue is Transit Van2. Van1 drove more runs and more miles than Van2, because Van2 had persistent steering issues that were unable to be fixed for several months.

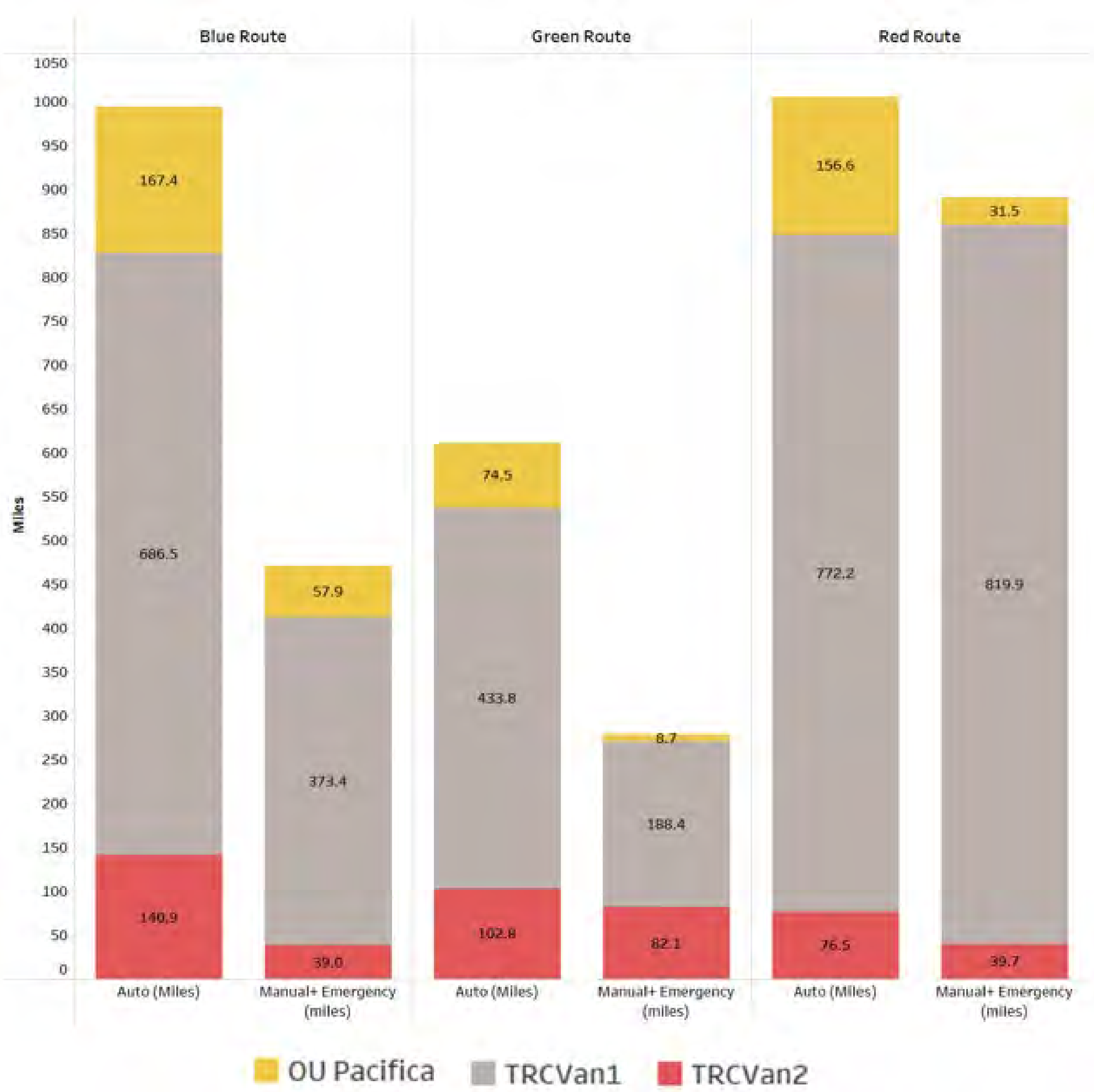

FIGURE 21 – NUMBER OF MILES DRIVEN IN AUTOMATED MODE

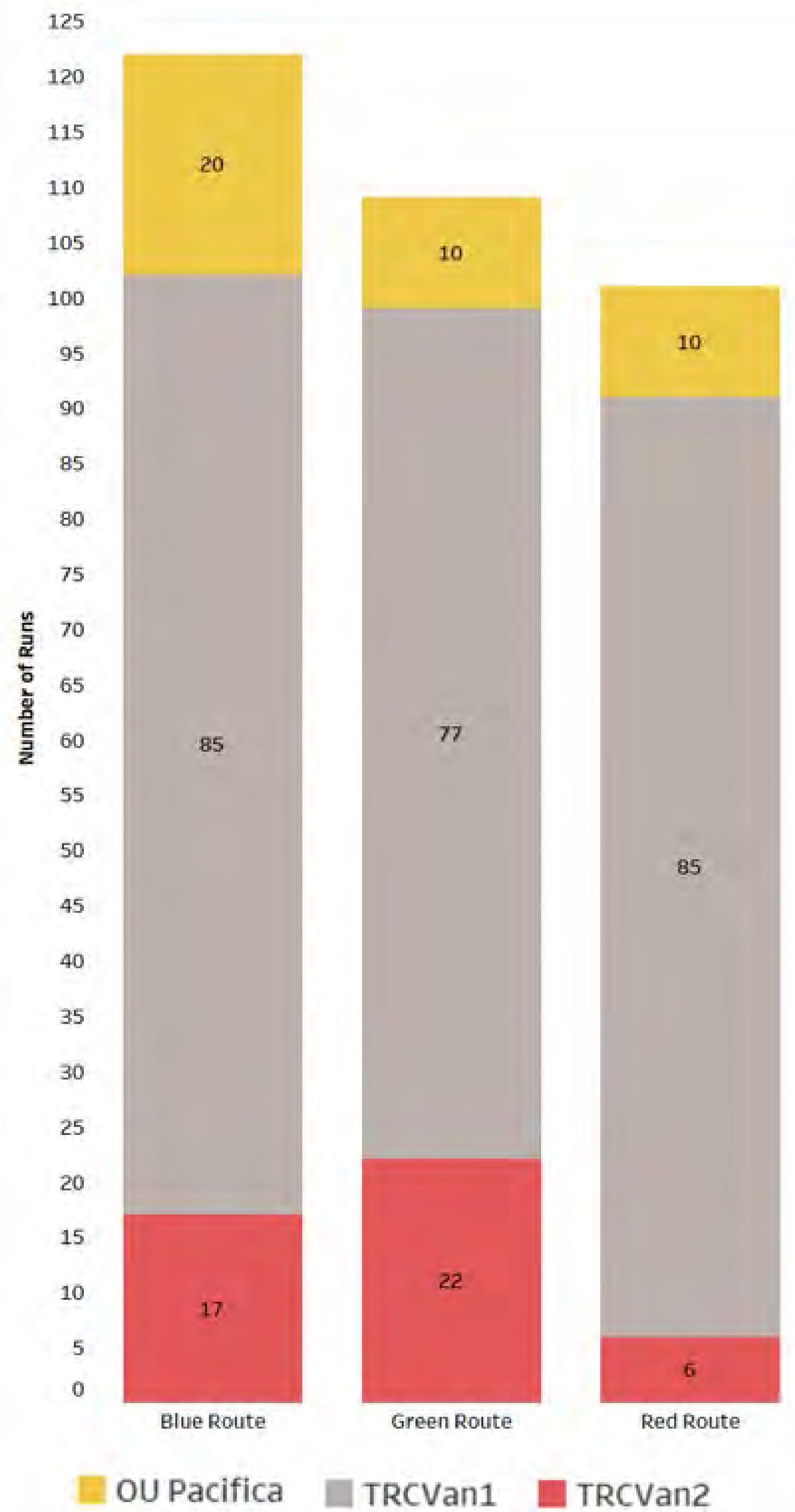

FIGURE 22 – NUMBER OF RUNS BY EACH VAN ON EACH ROUTE

3.8 Performance Measures and Key Performance Indicators

Several performance measures for the ADS passenger vehicles can be used for evaluating the readiness and efficacy of autonomous vehicle technologies in real-world scenarios. These measures help establish whether ADS-equipped vehicles are safe, efficient, and user-friendly.

These performance measures cover various aspects of vehicle and ADS operation, from basic driving tasks to complex interactions with traffic, pedestrians, and environmental conditions and are part of the following performance areas:

- Safety. Including measures such as the rate of accidents, near-misses, and adherence to traffic laws to assess the safety of ADS.
- Reliability. Evaluating how consistently and dependably ADS functions under different scenarios and conditions. Assessed through metrics such as disengagement frequency and ADS active versus inactive ratios.
- Efficiency. Assessing how ADS optimizes fuel usage, reduces travel time, and manages route planning.
- User Experience. Gauging passenger comfort, ease of interaction with the ADS, and overall satisfaction.

Based on the key performance areas, the project focused on the following five performance measures. Key Performance Indicators (KPI) for each measure are included in Appendix B7:

1) Localization. This is the capability to accurately determine the vehicle's position relative to the environment, and its exact location on a map and its orientation in space. Localization utilizes GPS, IMUs, and sensors like LiDAR and cameras, and is essential for path planning and navigation, where accurate and precise localization influences object detection and tactical maneuvers.
2) Object Detection. This is the capability to identify and categorize objects in the vehicle's surroundings. This includes other vehicles, pedestrians, bicyclists, animals, and static obstacles. Object detection relies on sensors like cameras, radar, and LiDAR and is critical for obstacle avoidance and decision-making. Several KPIs can be used to assess and monitor object detection (for example, the number of instances where objects were undetected).
3) Disengagement. A disengagement occurs when the driver intentionally takes over control from the ADS. This can happen for safety or system inadequacy reasons. Monitoring disengagements is crucial for understanding the reliability and safety of ADS. Important aspects of this measure are the reason the disengagement occurred, when and where it occurred.
4) Planning. This is the capability that is involved in determining the path and actions the vehicle will take to reach a destination safely and efficiently, considering real-time traffic conditions, road rules, and environmental factors. Planning involves route planning, behavior planning, and decision-making algorithms and is integral to safe and efficient navigation.

5) Motion Control. This is the capability to execute the planned path by controlling the vehicle's speed, direction, and movement. This involves actuating the throttle, brakes, and steering and directly affects ride comfort and safety. Motion control relies on precise control algorithms and feedback from vehicle sensors. Several KPIs can be used to access and monitor motion control (for example, the smoothness of the ride, and measurements of excessive accelerations or decelerations).

3.9 Insights from Collected Data and Driver Teams

The TRC and OU teams drove the three vehicles in the project on the Blue, Red, and Green Routes from mid-2023 until the end of February 2024. Each vehicle had a 3-person crew, one to drive and the other two to operate the on-board computers and monitor Apollo's Dreamview screen. The data for each run was recorded, uploaded to Amazon S3, and converted to databases and files for visualization and further analysis. Drivers were interviewed near the end of the deployment period and their feedback is noted in Appendix B8 and Appendix B9, respectively. Integrating the feedback from the driver interviews with KPIs offers examples of ADS performance in real-world rural environments. This section discusses qualitative insights from ADS operators and quantitative KPI data to provide a nuanced analysis of system performance during the deployments.

- ADS Activation and Engagement
    - Observations. Operators reported a learning curve in becoming comfortable with ADS. They initially needed to maintain control but gradually trusted the system's capabilities. Drivers reported about 40 hours of operating time to feel comfortable with the engagement and disengagement.
    - KPI Analysis. The ratio of ADS active versus inactive times and instances of ADS failing to activate when requested are critical for understanding system reliability. Initial operator hesitance and a high rate of successful system activation indicate adequate system reliability after operators become familiar with the system. The percentage of ADS Active (autonomous) well over 60% illustrates that reliability.
- Object Detection and Response
    - Observations. The vehicle had limitations in its ability to predict surrounding vehicles' paths and to react to dynamic events. The ability to respond to objects was limited, especially at higher speeds. However, it had limitations under certain conditions, such as high speeds or obscured sensors. This led to more frequent disengagements in urban areas that tended to have more traffic, more intersections, and more pedestrians.
    - KPI Analysis. Quantitative object detection and response effectiveness measures indicate limitations which highlight the necessity for continuous system refinement to address these limitations.

- Tactical and Operational Maneuvers
  - Observations. While ensuring compliance, the ADS's adherence to speed limits sometimes required disengagement to align with traffic conditions or to perform driving maneuvers safely. On some of the rural roads, especially the Green Route, the other traffic was used to the roads and tended to drive faster than the speed limit. Traffic sometimes queued up behind the ADS vehicle in automated mode and the other drivers appeared frustrated. The vehicle had difficulty at some intersections and the ADS drivers often had to take over to go correctly through the intersection.
  - KPI Analysis. Evaluating the ADS's performance in executing tactical and operational maneuvers reveals its capability to navigate traffic conditions within its operational design, even though with occasional adjustments and sometimes with disengagements or diversion maneuvers, the operator needs to ensure optimal traffic flow and safety.
- Ride Smoothness
  - Observations. Operators pointed out challenges related to vehicle dynamics, particularly in scenarios requiring delicate control, highlighting areas for improving passenger comfort and ride experience. Sometimes the vehicles stopped more abruptly than a normal driver would and sometimes the vehicle's autonomous braking was harder than normal, reducing the smoothness of the ride.
  - KPI Analysis. Instances of excessive acceleration, deceleration, and lateral movement highlighted areas where the ADS's handling needs to be refined to enhance ride smoothness and safety.
- System Disengagements
  - Observations. Various scenarios required manual disengagement, including unanticipated behaviors on the road and limitations in the system's environmental sensing capabilities. The three vehicles collected data related to disengagements during deployment. Some of the results and insights are described below. Appendix B2, Appendix B8, and Appendix B9 provide additional information.
  - KPI Analysis. The frequency and reasons for disengagements, as captured by the system, provide insights into operational challenges and areas needing improvement, highlighting a need for enhanced predictive capabilities and environmental adaptability.

3.10 Disengagements Analyses

The project team spent more time dealing with and analyzing disengagements than any other measure of system performance. This section includes data summaries that help demonstrate the importance of disengagements and the difficulty of analyzing them. The data showed a disengagement occurring whenever the driving mode or state changed from automated to manual. This could be driver-initiated or system-initiated. Over the approximately 10 months of deployment, the three passenger vehicles conducted 331 runs. Of those, 246 runs had at least one disengagement (74.5% of the runs). There were 726 disengagements during those 246 runs. Three runs were fully automated with no disengagements. The average number of disengagements per run with at least some automation was 2.91. For the 246 runs with disengagements, the average rate of disengagements per mile driven was 0.816 and the average number of miles between disengagements was 1.34 per mile. Many disengagements were short, a matter of seconds, and sometimes represented a failure of the system to reengage correctly. There were differences in the number of disengagements among the three vehicles and the three different routes, as shown in Figure 23.

This section also discusses the reasons for disengagements and the ways project participants looked at reasons on the different vehicles. The Transit vans' (called Van1 and Van2 in the data) operators used buttons in Dreamview to record approximately 10 different pre-selected disengagement reasons and operator notes (Appendix B2). In addition, the Transit van operators recorded text information about disengagements or unusual vehicle performance and placed that information on an Asana board of the project (see the TRC Driver Notes Appendix B8). In the TRC team's analysis of disengagements, 'Unknown' was often listed as a reason and was third most after 'Location' and 'Other.' For most of these disengagements, the operators entered reasons for disengagement as a text entry. After the run, the manually entered text reasons were evaluated and potentially assigned a different new reason. The Pacifica operators recorded the information onto a recorder and subsequently input the data with timestamp into the system (Appendix B9). The Pacifica operators also many times recorded the reason as 'Unknown.' For all vehicles on all routes, the disengagement data entered into the system had timestamps which allowed analysis of the time and location of a disengagement as well as the reason. Understanding the disengagements and where they occurred was an important part of the analysis and sometimes of determining a reason.

Once entered into the system, reasons were stored in the drive_event topic. Analysis of the contents of the drive_event topic yielded interesting information. There were 1,243 distinct events recorded in the drive_event topic for the 331 runs. Of those, 726 were determined to be disengagement events since they represented changes from automated to manual mode. Many had reasons indicated, but 229 events had Null for the reason, meaning that it was unknown, as with the Unknown and Other reasons mentioned above.

An interesting analysis of a single run shows some of the intricacies of disengagements. It shows drive events data for a run by Van1 on the Red Route in which there were 12 disengagements within 29 minutes. Each one is listed in Table 7 with the time it occurred, the reason, and the time to the next event. The run described is an example which shows that understanding of reasons needs more detailed analysis than could be completed within the project.

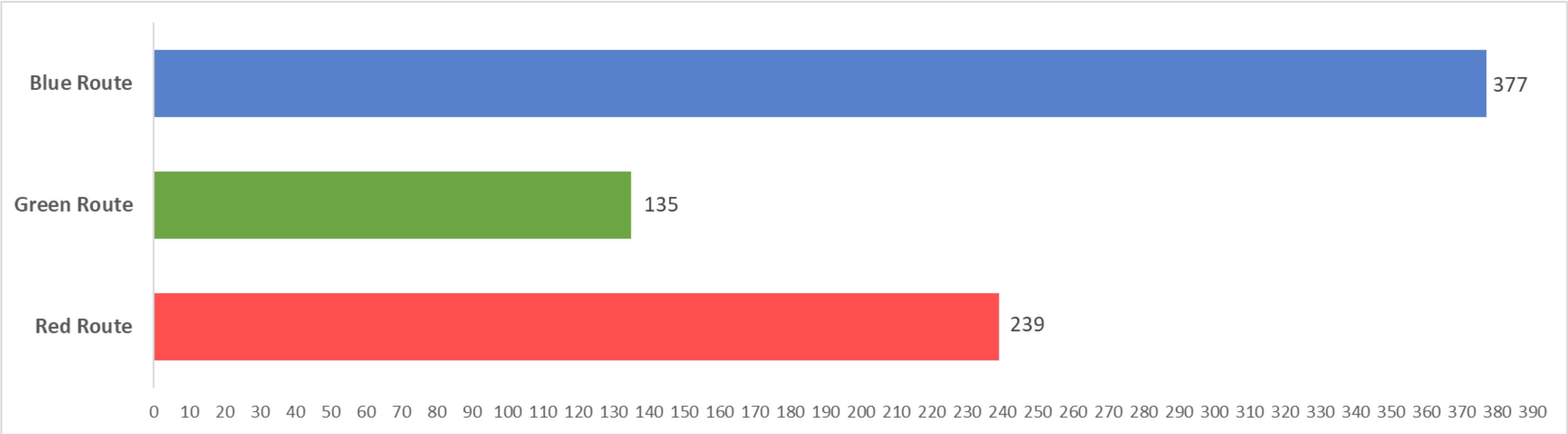

FIGURE 23 – TOTAL DISENGAGEMENTS BY ROUTE

TABLE 7 – SEPTEMBER 19, 2023 RED ROUTE VAN1 RUN – DISENGAGEMENTS

Time of Event	Drive_Event Data	Time between Disengagements
4:11:35 pm	Oscillation	
4:16:41 pm	Oscillation	5 min 6 sec
4:25:28 pm	over centerline on r/h curve	8 min 47 sec
4:26:02 pm	oncoming traffic hugging ctr	0 min 34 sec
4:26:43 pm	tug on wheel	0 min 41 sec
4:28:15 pm	over white line	1 min 32 sec
4:33:46 pm	Oscillation	5 min 31 sec
4:36:02 pm	traffic stopped on side of road	2 min 16 sec
4:36:53 pm	traffic approaching quickly from behind van	0 min 51 sec
4:38:37 pm	Null	1 min 44 sec
4:39:45 pm	Exiting without anchor	1 min 8 sec
4:40:01 pm	Exiting without anchor	0 min 16 sec

Figure 24 shows the number of disengagements for Van1 and Van2 for each of the new reason categories based on the text entries. The Red Route has many hills, ravines, and is a narrow, curved road with poor cellular network coverage in some sections. Thus, more localization disengagements occurred on the Red Route than on the Blue and Green Routes. On the other hand, runs on the Blue Route reported more object detection related disengagements, since that route passes through downtown Athens and other areas in the town with higher pedestrian and vehicle traffic as compared to the other routes and as shown in earlier figures and maps.

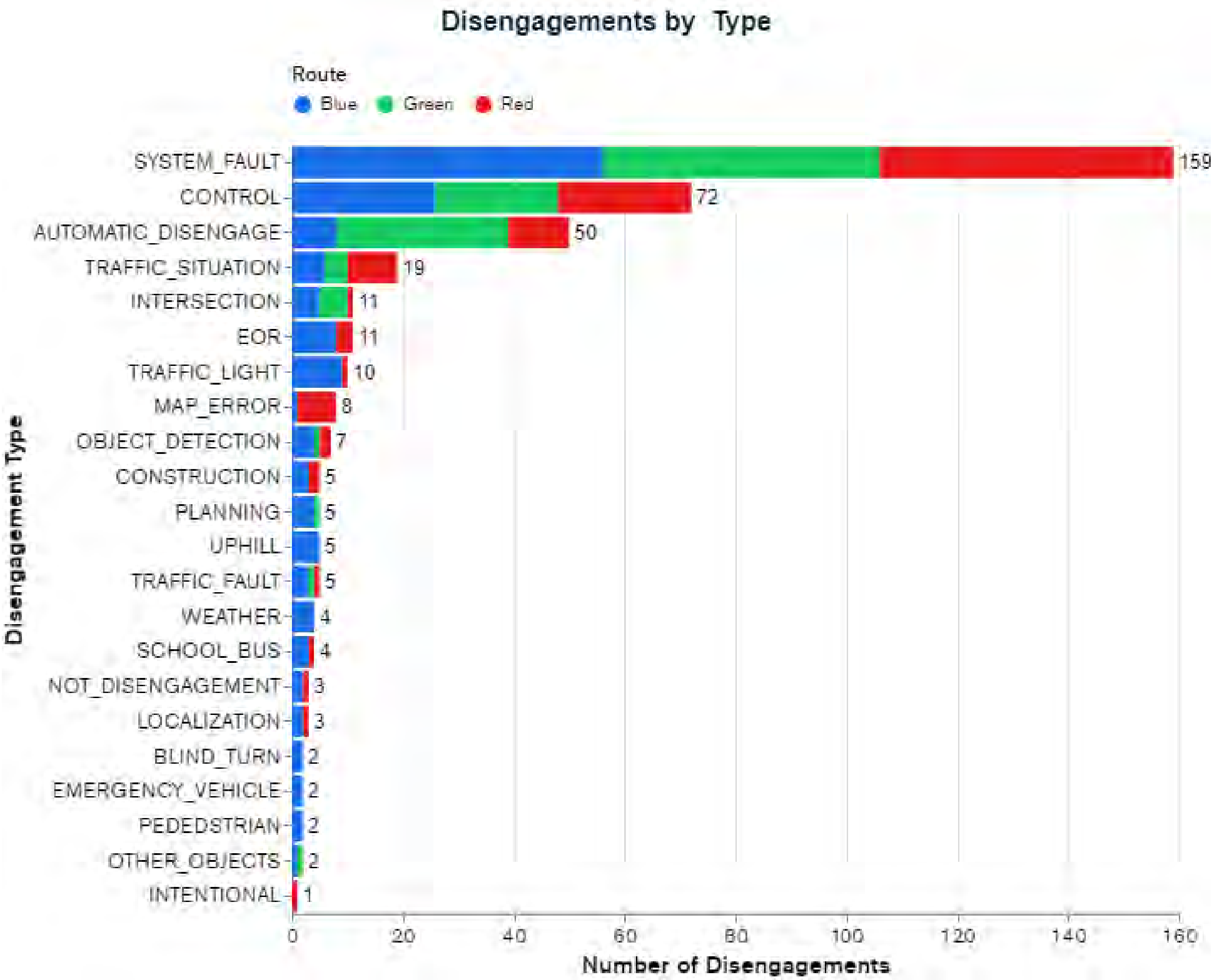

FIGURE 24– DISENGAGEMENT REASONS FROM TEXT ENTRIES FOR ‘OTHER’ AND ‘UNKNOWN’

To understand how disengagements are related to location on a route, the project teams for all the automated vehicles plotted disengagement reasons on the route map. Figure 25 shows the locations along the Blue Route where Transit vans’ disengagements occurred with color coding for the disengagement reason. The legend shows the drive_event reasons determined by TRC analysts. The report in Appendix B2 has additional maps of disengagement locations on the Red and Green routes and a more detailed discussion of reasons for disengagements.

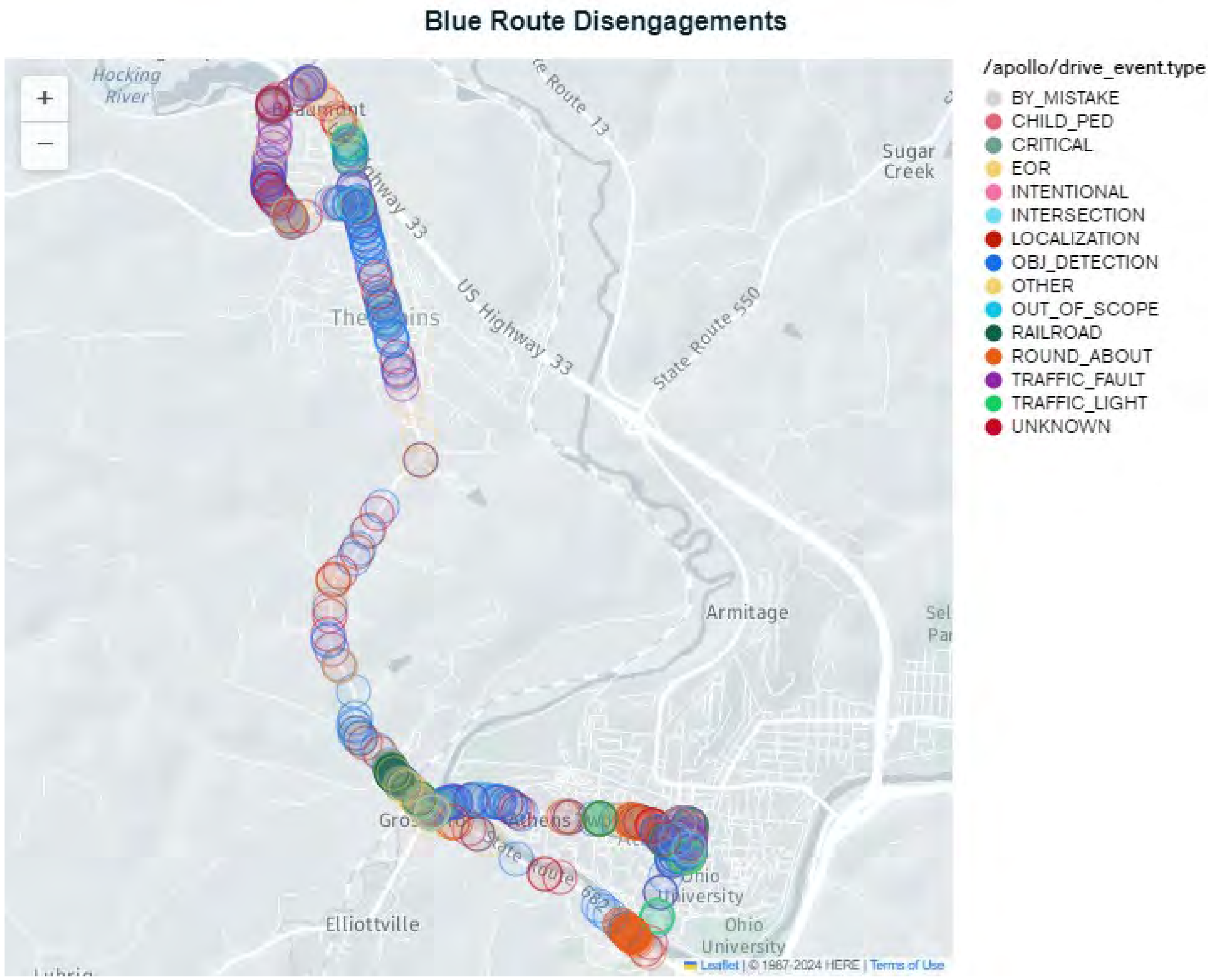

FIGURE 25 – DISENGAGEMENT REASONS ON BLUE ROUTE

OU and students from YSU analyzed the collected data, particularly disengagements involving the Pacifica. YSU plotted data points to show on maps where disengagements occurred. The OU map (Figure 26) shows takeovers as some of the reasons for the disengagements. Just as the Transits' diagram above shows activity at the upper and lower points on the Blue Route, Figure 26 shows Pacifica disengagements in the primarily urban areas.

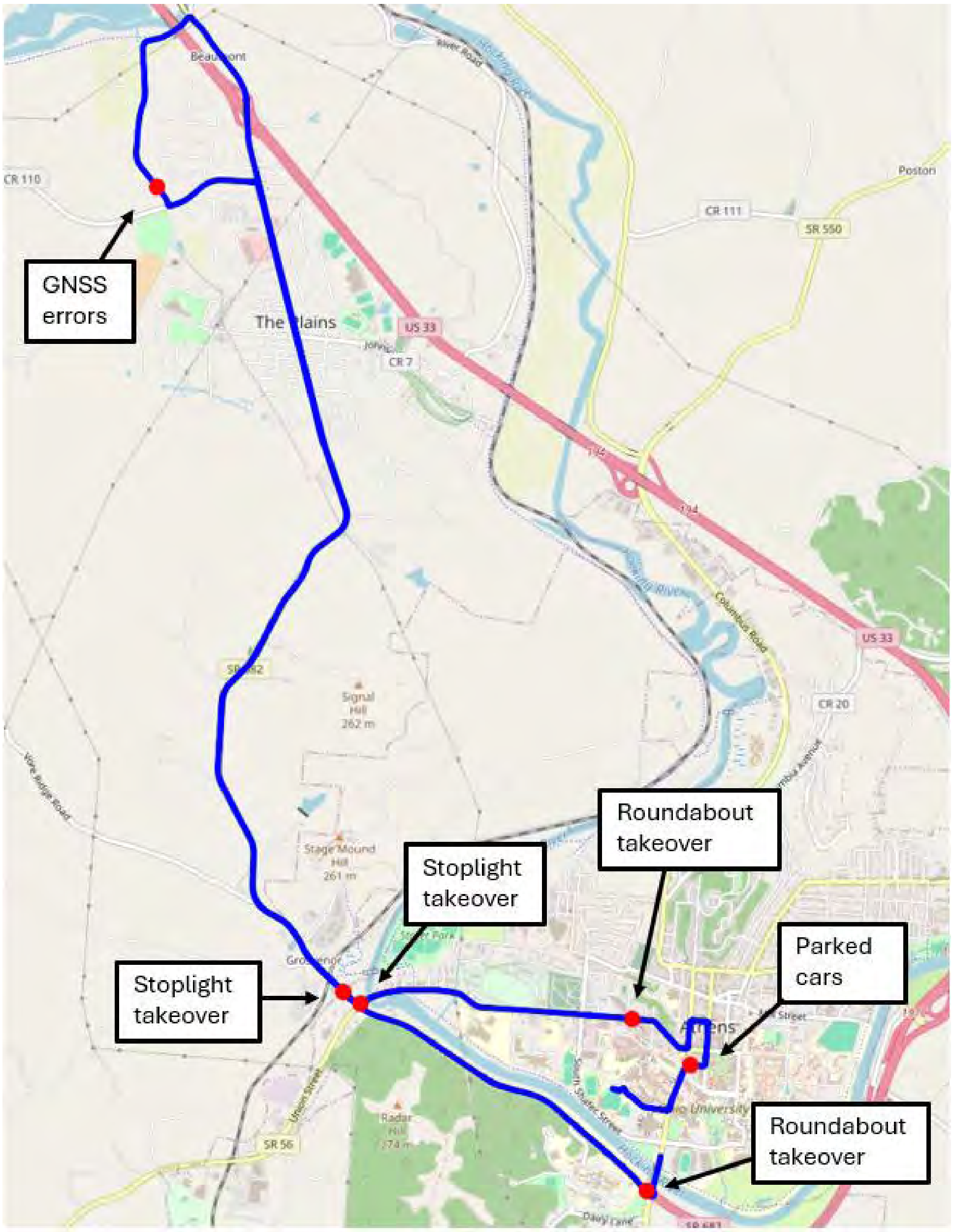

FIGURE 26 – MAPS SHOWING AREAS OF DISENGAGEMENTS AND CONTRIBUTING ENVIRONMENT

In another YSU analysis, team members wrote a script to log 502 disengagements they analyzed with location, time, and a map screenshot and compiled the information into a spreadsheet that allowed a multi-select dropdown columns so analysts could document what features were present at each disengagement. Table 8 notes a list of features that could have been at a disengagement and how frequent those were. While no cause-and-effect conclusions were drawn from the data, the analysis adds to the project's understanding of disengagements and their significance and shows the utility of future analysis of the data.

TABLE 8 – YOUNGSTOWN STATE ANALYSIS OF DISENGAGEMENTS INVOLVING ROUTE FEATURES

Feature	Frequency Count	Percent of Disengagements
Other/unknown	169	33%
Intersection	147	29%
Downtown	103	20%
One Way	93	18%
Left Turn	90	18%
Right Turn	75	15%
Roundabout	46	9%
Localization	44	9%
Railroad	22	4%
Underpass	7	1%

3.11 Conclusions or Takeaways from Passenger Vehicle Deployments

From the deployments of the three vehicles in Phase 2, the project team identified the following takeaways:

- Driver Team and Devices. The deployment vehicles required a driver and two assistants to work with the software and visualization technologies. The project partners implemented additional displays or buttons so that the driver could be kept better informed about the vehicle operation. The driver teams stayed diligent throughout the runs, and it was their attention to system performance that resulted in the percentage of automated miles being more than 63 percent of the total.
- ADS Adjustments during Operation. Automated mode is based primarily on the maps and route selected to the destination with no adjustment possible by the operator when the system is operating. The ADS software stack cannot adjust based on surrounding features, nor does it consider outside factors such as heavy traffic or weather or road work zones. Human driving behaviors are typically adjusted for these considerations and others. Manual takeover by disengaging was the only way to adapt to surrounding traffic behavior. The functionality to enable drivers/operators to apply an adjustment to the system for traffic conditions including speed would be helpful. Allowing the drivers to adjust the maps or waypoint following to account for potholes, construction, parked cars, or unmarked pedestrian crossings could also improve vehicle operation.
- HD Maps. Operation in automated mode is dependent on accurate maps that include speed limits on sections of the route. The project team provided much information early in the deployments to the map supplier to improve the accuracy and correctness of the maps. Nevertheless, local features, such as cresting a hill with a sharp incline change and intersection layouts need to be represented in

the maps. Speed limits included in the maps did not necessarily represent the behavior of other traffic which complicated operations involving other traffic.

- ADS Speed Limits. Vehicle software stacks and the maps were designed to operate at the posted speed limit. This appeared to frustrate surrounding drivers who were used to the route and wanted to travel faster. Conversely, the speed limit on some sections of the routes was sometimes greater than the vehicle drivers felt was safe. In the populated urban areas, other drivers were often more cautious and drove below the speed limit while the automated vehicles drove at the speed limit.
- Intersections. The vehicles in automated mode had difficulty navigating roundabouts and traffic signals. While the vehicle could sometimes detect traffic signals, other objects around the traffic signals at intersections often caused confusion for the project vehicles. The vehicles also had difficulty with intersections with any type of upward and downward slope. The project team implemented a traffic light monitoring light so that the driver would know if the vehicle detected the light correctly and could disengage as needed. Drivers noted the importance of being ready to respond by disengaging at traffic lights depending on how many cars were stopped and how fast the project vehicle was approaching the intersection.
- Objection Detection. The vehicles had difficulty detecting large objects such as trucks and small objects. Detecting was usually more difficult at higher speeds. Drivers had to disengage often if the vehicle did not slow down sufficiently when approaching an object.
- Vehicle Performance. Generally, the vehicles performed better, and the drivers were more comfortable at lower speeds in less populated areas with fewer surrounding vehicles and objects. The automated software could not adjust to traffic and the uncertainties of what other vehicles might do. This led to many disengagements in populated areas or intersections. Conversely, autonomous driving and driver confidence were high on the Green Route which had fewer people and intersections.
- GNSS Improvements. Having consistent data/GPS connection in rural areas is a critical area of concern for reliable automated operation. Localization was a problem in some segments of the routes. The project team enhanced the vehicle sensor to improve GNSS, but areas existed where the signal was lost, and the drivers had to disengage the automation.
- Disengagement Areas. Project team drivers had to disengage more often in populated areas where other vehicles or pedestrians were present. The Blue Route had more disengagements than the other routes. Disengagements were also common in hilly, curvy, or tree covered areas if GNSS was lost.
- Reasons for Disengagements. The project developed a lot of detailed information about the reasons for disengagements, including where they occurred on the various routes. The most common disengagements involved localization when the path of the vehicle strayed too far from intended due to loss of GPS and/or cellular signal for corrections, object detection when something outside the vehicle presented a potential risk, and behavior of surrounding traffic or pedestrians. The stored

data for the project includes many reasons for disengagement and allows determination of the time and location of the disengagement. This reason information should be useful to future researchers.

3.12 Additional Analyses Related to Passenger Vehicles

3.12.1 Incorporate Results of GPS and Related Location Enhancements

To follow path plan, navigate intersections, and stay centered in the lane required the ADS vehicles to have horizontal accuracy of less than 0.5 meters to confidently stay in the lane with the system engaged. Rural environments such as the Red Route in particular exhibit several challenges for GNSS/INS systems, requiring redundancy of data to calculate precise location solutions and be able to operate under partial or complete satellite obstructions.

The TRC team investigated several different localization enhancing technologies including ZED-F9R which can use all four GNSS constellations for vehicle positioning. It can receive corrections, from either RTK using a local base station or from an NTRIP service, or from U-Blox's satellite-based service Thingstream and has an integrated IMU. This allowed high satellite reception in challenging areas. The enhancements showed it is possible to have low-cost position accuracy with improved performance.

Further integration is needed to incorporate the enhancement technology into ADS vehicles. The details of TRC's investigation are included in Appendix B2.

3.12.2 Highlights of Collected Weather and Related Data on TRC Test Track

Most of the deployments were carried out in good weather. However, the project team conducted three CE tests at TRC Inc.'s SMARTCenter during a snowstorm to understand how the object detection capabilities were hampered by the snow. The three tests included a stationary obstacle (a sedan) and moving obstacles. For safety reasons, the tests were conducted at slow speeds (less than 45mph) in manual mode.

The TRC team observed that the object detection module was tricked by the cloud of snow from the front vehicle into detecting objects that did not exist. An example is shown in Figure 27 with a video comparison in Figure 28. The object detection algorithm was tricked by the snow cloud to detect objects that did not exist.

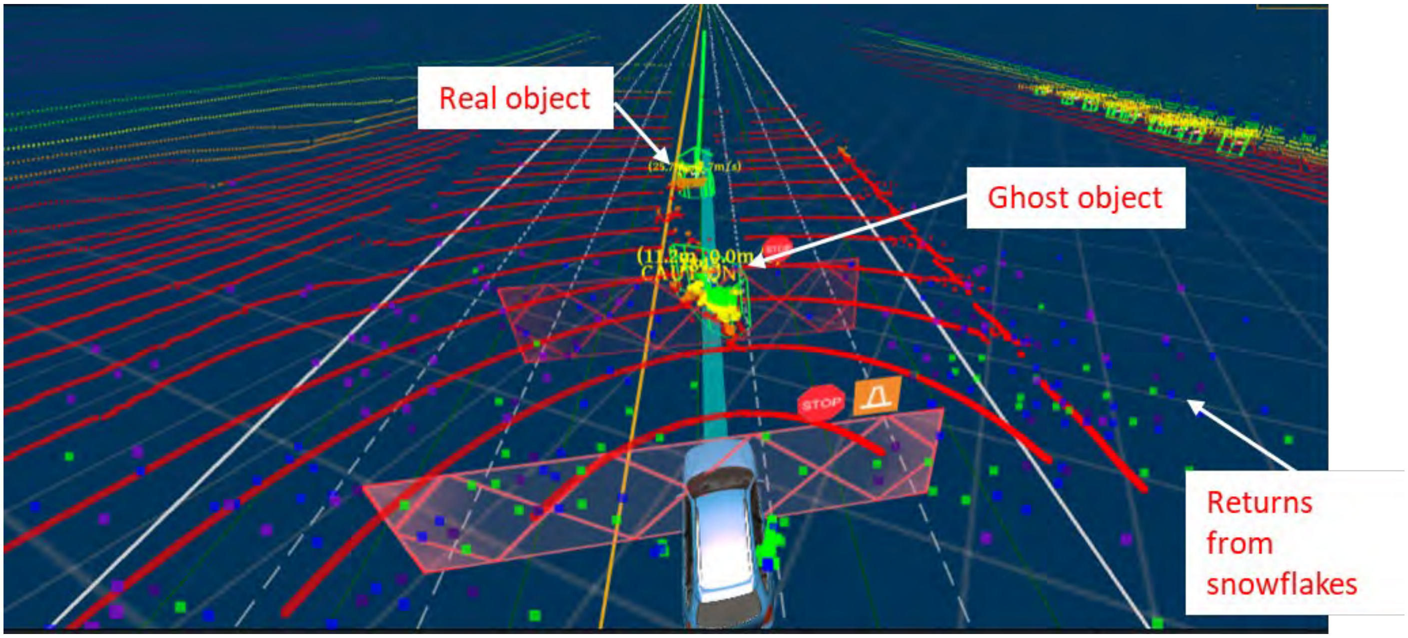

FIGURE 27 – OBSERVATION FROM TESTS UNDER SNOWY CONDITIONS

FIGURE 28 – PHOTOGRAPH OF OBJECT FROM CAMERA DURING SNOW TEST

3.12.3 Results of Human Factors Evaluation of Passenger Vehicle Drivers

As part of its work with the Pacifica ADS deployments, OU added special glasses for the drivers and collected and analyzed eye movement data related to disengagements. This additional work is documented in Appendix B10. For this additional data collection, eye tracking was performed using Tobii Pro Glasses 3 equipped with cameras integrated in the lenses for pupil tracking and an outward facing camera to record the driver point of view. During post-run data analysis, the OU team analyzed object detection data and the recorded reasons for disengagement to assess how the recorded eye movement data related to disengagement. Gaze results showed that the driver was highly attentive to their surroundings with most of the event time being used to scan the outside environment instead of focusing inside of the van. Figure 29 shows some sample data with the driver's gaze on a vehicle in an approaching roundabout.

FIGURE 29 – PHOTOGRAPH OF HUMAN FACTORS FOCUS SPOT

3.12.4 Data Mining with Youngstown State University

During 2023, DriveOhio implemented a partnership with multi-disciplinary students from YSU. The YSU team consisted of graduate and undergraduate students, a graduate student teaching assistant, and a professor as advisor. The team had advisors from TRC, OU, and DriveOhio to guide the way. The main goal of this partnership with YSU was to get a head-start on post-deployment data analysis. The YSU students were given access to the Amazon DynamoDB dataset from the Pacifica deployment runs, primarily on the Blue Route, and Amazon WorkSpaces virtual desktops were provided to each student for easy access to the Amazon S3 buckets and the indexed dataset in Amazon DynamoDB. The students developed familiarity with NoSQL and various tools including MongoDB/Amazon DynamoDB, Amazon S3, different python libraries, weather provider APIs. The team also learned the use of HD vector maps and Google Maps, as necessary. They further leveraged pymongo and boto3 python libraries to query and search necessary data from the database. In weekly meetings with project personnel, YSU discussed potentially challenging areas on the deployment routes where the vehicles had non-ideal performance, particularly related to disengagements from automated mode.

As an early 2024 output of their work, the YSU students prepared a poster for a conference at Purdue University. The poster provides a useful summary of some of what the students worked on into the first few months of 2024. Some of the results of their analysis of disengagements have been integrated into the earlier disengagements discussion in Section 3.10. It is anticipated that their work with the Ohio Rural ADS Project data will continue.

4.0 Stakeholder Feedback

Collecting feedback information from groups of people who interact with ADS technology was crucial to evaluating its application and safety, in addition to developing and informing future rulemaking. To kick off this engagement, the project team developed an initial Communication & Outreach Plan to provide general guidance on how and when to reach stakeholders and end-users (Appendix C1). This included identifying audiences and coordinating engagement opportunities. The project team adapted their engagement strategy and methods to be flexible with the project's changing needs and goals. From the beginning of the project, key stakeholders were engaged through end-user focus groups, a local and regional stakeholder workshop, and selected interviews, and then were kept informed as the project progressed.

4.1 Early Focus Group Meetings

To determine end users' needs, ideas, and concerns, the project team conducted seven focus groups between April and July 2021. Results were used to develop the Concepts of Operations for both the truck platooning system and the L3 passenger vehicles. End user participants included 40 representatives from national, state, regional, and local organizations:

- Buckeye Hills Regional Council
- Central Ohio Logistics Council
- City of Athens, Ohio (City Council, Fire and Police Departments)
- DriveOhio/ODOT
- Federal Highway Administration
- Federal Motor Carrier Safety Administration
- Federal Transit Administration
- Gallia County Engineer
- Ohio Department of Public Safety
- Ohio State Highway Patrol
- ODOT Central Office
- ODOT District 10
- Ohio Trucking Association
- Ohio University
- SIXMO City Services
- Southeast Ohio Port Authority
- Terra Sound Technology
- USDOT Volpe Center

Focus groups were organized into five categories – logistics and planning professionals, USDOT, Southeast Ohio local partners (2 focus groups), ODOT/Drive Ohio (2 focus groups), and state safety officials. A benefit of holding the focus groups was that they created awareness and understanding of the project.

Once all user needs were collected, the project team reviewed and applied this information, as applicable, along with other project data to develop operations concepts, use cases and test routes, and further analyze the ADS technology. A high-level overview of end user needs which consisted of comments, questions, and key takeaways from all seven focus groups is included in Appendix C2. Key examples include:

- Truck platooning technology is not yet in production, but is there a business case or freight density or expected return on investment?
- Truck drivers are afraid of losing jobs to automation, but there is skepticism about Level 2 being any more than cruise control on steroids.
- Automated vehicles are not distracting to other travelers when there are "drivers" in the automated vehicle, but once the "person" is removed it becomes alarming.
- How does the vehicle interact with or communicate its intent to other road users?

4.2 Rural Automated Driving Systems Workshop

To meet the communication and outreach goals of developing a dialogue with community leaders, informing local jurisdictions about the demonstration findings, and soliciting input to determine rural mobility challenges and needs, a stakeholder workshop was held on January 18, 2023 in Athens, Ohio. The meeting's purpose was to inform stakeholders about the upcoming passenger vehicle deployments on the three selected routes, the data gathering process, and seek their input on possible uses of automated technology in the future. The targeted audience for the workshop included local elected officials, transportation officials, local healthcare, and transit and social service agency leaders. Workshop attendees included the following organizations:

- City of Athens, Ohio
- Greater Ohio Policy Center
- Hocking Athens Perry Community Action – Athens County
- Hocking Athens Perry Community Action – Hocking County
- JobsOhio
- Meigs County Jobs and Family Services
- Morgan County Mobility
- ODOT District 10
- OU
- OSHP
- Local law enforcement

Workshop participant feedback was collected through worksheets and key table takeaways. A key question discussed was how an automated vehicle might overcome challenges in rural communities. Comments included providing transit alternatives to those who do not drive, improved safety, and delivery of food or medical items to remote areas. A detailed meeting summary of this workshop can be found in Appendix C3.

4.3 Survey and Focus Groups for Mobility Challenged Community

Another supporting task within the project involved focus groups of primarily older Ohio residents to gather information about their opinions about automated vehicles and how they might view riding in such vehicles. Appendix C4 contains the results of focus group surveys conducted by OU during the project. Generally, the focus group participants had little prior knowledge of automated vehicles and after presentations describing the capabilities of such vehicles, some felt they would be comfortable riding in an automated vehicle. Most of the meetings had a Transit or Pacifica van on display.

4.4 High School Essay Contest – Partners for Automated Vehicle Education

High school students in the Athens area were invited to write essays about how automated vehicles could benefit their communities. The contest was sponsored by the Partners for Automated Vehicle Education (PAVE). The essays were reviewed and scored by industry experts with the top three papers receiving scholarships.

5.0 Conclusions

This section summarizes the highlights of the conclusions and during the Ohio Rural ADS Project. It also looks back at the original Notice of Funding Opportunity (NOFO) Automated Driving System Demonstration Grants from USDOT to show that DriveOhio and its project team met the goals and requirements of the original USDOT NOFO.

5.1 Summary of Conclusions

5.1.1 Truck Platooning Technology

- The host fleet was pleased with the performance of the truck platooning technology in its regular revenue service and would be interested in continuing to use the technology. The technology was operating on Ohio public roads and the truck platooning-capable tractors were driven by the host fleet drivers in two tractor sets. The host fleet did suggest that longer hauls are needed for such technology and harmonization of regulations in multiple states would be the next step. Lastly, the host fleet drivers did not notice any difference in other vehicle cut-in patterns when operating the technology.
- The truck platooning-capable tractors performed well and only experienced six excess braking events in 11,486 miles of operation with the technology turned on. While there are a number of other vehicle cut-ins, no incidents that adversely affected the truck platooning operations occurred. The project collected vehicle operating and video data while in truck platooning mode on public roads, one of the major deliverables of this project.
- Law enforcement was pleased with the operation of the chicken lights to show that the trucks were engaged in truck platooning mode. One of the OSHP's goals was to expose automated vehicle technology to all levels of law enforcement. OSHP suggests that chicken lights be standardized on higher level automated vehicles to assist other drivers and law enforcement safety activities.

5.1.2 Passenger Vehicle Level 3 Technology

- The passenger vehicles drove 3,822 miles during the demonstration on three rural public road, project-designated routes totaling 42.1 linear miles near Athens, Ohio, with 68.3 percent of the mileage in automated mode. Disengagements were frequent because of traffic, intersections, road configuration, or loss of GPS signals.
- Passenger vehicle technology and the HD maps were designed to operate at the posted speed limit. The speed limit on some sections of the routes was sometimes higher than the vehicle safety drivers felt was safe. In the populated small town urban areas, the project driver teams noted that other drivers were often more cautious than the automated vehicles.
- Generally, the vehicles performed better, and the drivers were more comfortable at lower speeds in less populated areas with fewer surrounding vehicles and roadside objects. The automated software was not optimal in its ability to adjust to traffic and the uncertainties of what other vehicles might

do. This led to many disengagements in populated areas or intersections. Conversely, automated driving and driver confidence were high on the Green Route (one of the three project designated routes) which had fewer people and intersections.

5.2 Goals

The NOFO included three goals related to projects that were funded. The following information indicates how the Ohio Rural ADS Project met the goals.

1) Safety. Test the integration safe integration of ADS into the Nation's on-road transportation system. Fund projects that demonstrate how challenges to the safe integration of ADS into the Nation's on-road transportation system can be addressed.
    a) The project team developed safety management plans for both truck and passenger vehicle demonstrations and adhered to the details of those plans.
    b) There were no safety incidents or problems during the demonstrations with the trucks covering 11,486 miles and the passenger vehicles 3,822 miles.
    c) Both the trucks and the passenger vehicles integrated well into the road network operation.
    d) The trucks operated in revenue service for clients throughout Ohio, driving on interstates, US routes (divided highways), and 2 lane routes in Ohio without adversely affected normal roadway operations. These routes were selected based on the safety management plan requirements and host fleet client needs.
    e) The passenger vehicles operated in a variety of roadway types in both rural and urban settings and in many cases on curvy roads with trees and normal traffic of those roads. The deployment was on three carefully selected routes near Athens, Ohio that included those roadway types. Prototype L3 automation operated more than 60 percent of the time on the rural and urban routes.
2) Data for Safety Analysis and Rulemaking. Ensure significant data gathering and sharing of project data with USDOT and the public throughout the project in near real time, either by streaming or periodic batch updates.
    a) Large amounts of vehicle operating and video data for both trucks and passenger vehicles were collected and uploaded to an Amazon Web Services cloud-based system under the responsibility of the ODOT.
    b) The data is additionally retained in Amazon DynamoDB tables collated by deployment runs with timestamps throughout that enable analysis of individual runs or groups of runs. Significant amounts of radar, LiDAR, and camera data (also timestamped) that allow visual analysis of the operation of the vehicles and the surrounding objects and traffic were also collected and retained for analysis.

3) Collaboration. This program seeks to work with innovative state and local governments, as well as universities and private partners, to create collaborative environments that harness the collective expertise, ingenuity, and knowledge of multiple stakeholders.
   a) The prime contractor was an office of ODOT specifically established to work on vehicle automation.
   b) There were numerous meetings throughout the project with state and local government stakeholders and private companies such as logistics firms and area logistics councils. Law enforcement was involved throughout the project to coordinate demonstration objectives and locations.
   c) Several universities played key roles in the project (OU, UC, UCLA, and YSU) and supported various aspects of the passenger vehicle demonstrations.
   d) There were several focus groups to discuss automation technology that included vehicle displays and press coverage.
   e) The project had industry partners providing vehicle automation software, factory tractors/vans, truck platooning hardware/software, and a test track offering testing facility service, as well as driver training.

5.3 Requirements

The NOFO included three requirements. The following information indicates how the Ohio Rural ADS Project met the goals.

1) Each demonstration must focus on the research and development of automation and ADS technology (per the SAE International definitions), with a preference for demonstrating L3 or greater automation technologies.
   a) The passenger vehicle demonstration was of prototype L3 automation technology, primarily using Apollo software with LiDAR for object detection and HD maps for path following. The three demonstration vehicles drove 2,611 miles in L3 automated mode.
   b) The truck platooning demonstration was of L1 automation technology working in revenue service and operated by an Ohio trucking company. The host fleet and its drivers operated the truck platooning capable tractors and found the technology to be useful to their operations.
2) Each demonstration must include a physical demonstration.
   a) Both the truck and passenger vehicle deployments involved operation on public roads with varying roadway types, both urban and rural.
   b) The trucks operated in revenue service for seven months, serving the host fleet's clients in revenue service.

   c) The passenger vehicles operated with existing traffic for ten months on three project-designated routes near Athens, Ohio selected for their variety of rural and small-town urban conditions.

3) Each demonstration must include the gathering and sharing of all relevant and required data with the USDOT throughout the project, in near real time. The recipient must ensure the appropriate data are accessible to USDOT and/or the public for a minimum of five years after the award period of performance expires.

   a) Both the trucks and passenger vehicles gathered and stored large amounts of vehicle operating data on cloud-based Amazon Web Services operated by ODOT, which will continue to operate a data access environment for the five-year data access period.

   b) Several meetings were held during the project to review data with USDOT personnel.

      The truck data was collected on an intermediate system and then converted to databases for storage and analysis on the ODE. While the passenger vehicle data was collected and initially stored in raw Apollo cyberbag format, it was converted to database format to facilitate future analysis. To facilitate analysis for both truck and passenger vehicle deployments, all data was timestamped so that individual vehicle runs could be analyzed and compared and data accumulated for trend and performance measure analysis.

Appendix A
Truck Platooning Supporting Documents

Appendix A1
Concept of Operations

TRUCK AUTOMATION CONCEPT OF OPERATIONS

Ohio Rural Automated Driving Systems (ADS) Project

Prepared for: DriveOhio

Prepared by: CDM Smith

Version 1.0 | April 4, 2022

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List of Acronyms

Acronyms

ABS	Anti-Lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving Systems
CACC	Cooperative Adaptive Cruise Control
CAN	Controller Area Network
CBI	Confidential Business Information
CI	Collision Incident
ConOps	Concept of Operations
C-V2X	Cellular Vehicle-to-Everything
DC	Distribution Center
DOT	Department of Transportation
EA	Excessive Acceleration
ETA	Estimated Time of Arrival
FMCSA	Federal Motor Carrier Safety Administration
HMI	Human-Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
KPI	Key Performance Indicator
L1	SAE Level 1 of Driving Automation
L2	SAE Level 2 of Driving Automation
OBU	Connected Vehicle On-Board Unit
ODD	Operational Design Domain
ODE	Operational Data Environment
ODOT	Ohio Department of Transportation
OEM	original equipment manufacturer
OU	Ohio University
PCM	Platoon Control Message
PGC	Platooning Gap Compliance
PII	Personally Identifiable Information
PMM	Platoon Management Message
RFP	Request for Proposal
RRV	Rules-of-the-Road Violation
RSU	Connected Vehicle Roadside Unit
SAE	SAE International, formerly known as Society of Automotive Engineers
SDC	Secure Data Commons
SDD	Safety Driver Disengagements
TEM	ODOT Traffic Engineering Manual
TTC	Time-To-Collision
TRC	Transportation Research Center
UC	University of Cincinnati

UC1-S1	Use Case 1, Scenario 1
UC2-S1	Use Case 2, Scenario 1
UC2-S2	Use Case 2, Scenario 2
UC3-S1	Use Case 3, Scenario 1
UC4-S1	Use Case 4, Scenario 1
USDOT	United States Department of Transportation
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

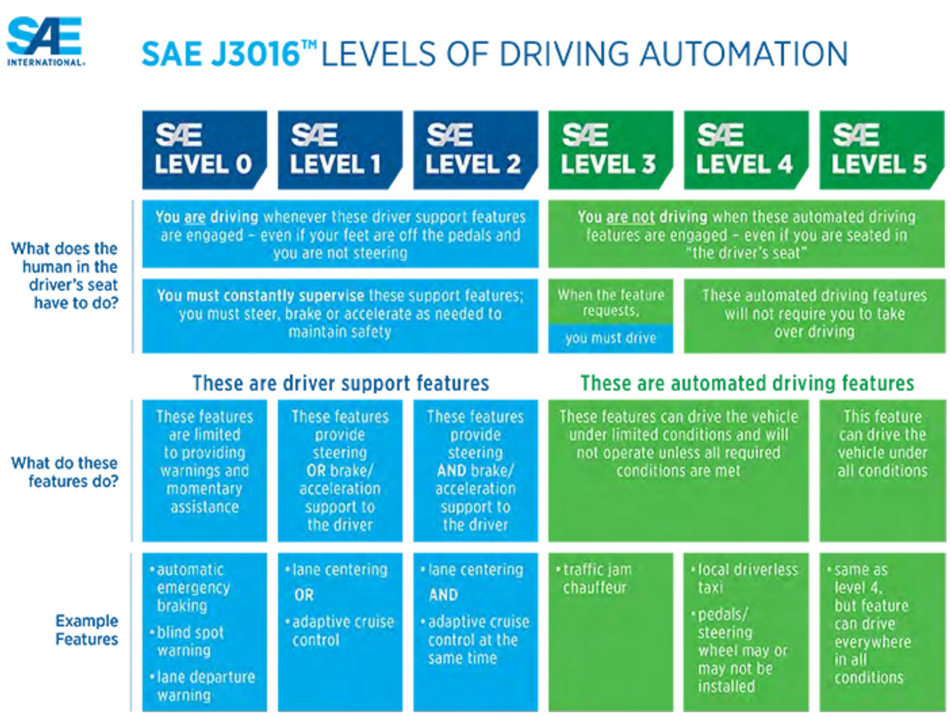
1.0 Scope

The U.S. Department of Transportation (USDOT) awarded a $7.5 million Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of the Ohio Department of Transportation (ODOT), JobsOhio, Transportation Research Center (TRC), Bosch, Ohio University (OU), University of Cincinnati (UC), and Southeast Ohio community partners. Ohio's ADS demonstration will pilot how automated vehicles could improve safety for drivers, passengers, and other travelers in rural settings. The grant funds two deployments: automated passenger vehicles and automated commercial trucks.

Automated driving systems have been extensively tested in urban areas, but much less so in rural settings. Hence, there is limited data about how such vehicles operate in rural environments, even though rural areas account for 97 percent of the nation's land area.[1] The Ohio ADS Demonstration Grant will help fill this gap by collecting, analyzing, and reporting data to USDOT to develop policies that improve safety and benefit rural regions in Ohio and elsewhere.

This document provides a Concept of Operations (ConOps) to deploy Level 1 (L1) and Level 2 (L2) automated trucks in Ohio. Figure 1 shows the Society of Automotive Engineers (SAE) International levels of automation. L1 and L2 include driver support features such as adaptive cruise control and lane centering. The driver is always engaged with the driving task.

Figure 1: SAE International Automation Levels



Source: SAE International

[1] U.S. Census Bureau *American Community* Survey, https://www.census.gov/programs-surveys/acs

The ConOps is a foundational systems-engineering document that identifies truck automation user needs, describes key user classes and stakeholders, and defines use cases describing how the system will operate. It also summarizes the expected impacts of truck automation on private and public sector stakeholders. The intended audience consists of system developers who will create a system based on the user needs and use cases identified herein, as well as anyone interested in the technical details of the truck automation deployment.

The scope of the project is to test L1 and L2 truck automation technologies including lane centering and truck platooning with a fleet partner. Lane centering helps drivers remain within the defined travel lane. Truck platooning involves two trucks traveling closely together in a cooperative manner, which can improve safety and fuel efficiency. System validation tests will occur on a closed test course prior to deployment on public roads. The pilot system will rely on radar and cameras to enable lane centering and platooning functionality. The pilot will gather data in both single truck and platoon modes; such data will support analysis of potential safety and efficiency benefits of the technology. System data may also be useful for preliminary assessment of L3 or L4 applications, but such deployments are outside the scope of this project.

The Ohio ADS Demonstration Grant also funded a Passenger Vehicle Automation deployment. The ConOps for that test is provided under separate cover.

The remainder of this document is organized as follows:

- **Section 1** summarizes the scope of the project and this document.
- **Section 2** describes the current system or situation in Ohio with respect to truck automation and identifies key project stakeholders and their roles in the deployment.
- **Section 3** identifies the truck automation user needs collected for this project.
- **Section 4** provides the truck automation concept including high-level functional definition, operational policies, and constraints (i.e., where/when the trucks can and cannot operate), and assumptions and challenges that may affect system development and testing.
- **Section 5** provides a series of use case scenarios that describe how the system is expected to operate in different situations.
- **Section 6** summarizes anticipated impacts on different stakeholders.
- **Section 7** offers conclusions and next steps for the project.

This structure is based on the Institute of Electrical and Electronics Engineers (IEEE) 1362-1998 standard, which outlines typical content for a ConOps. Some sections have been tailored to fit this project. It is also consistent with Section 13 of the Ohio DOT Traffic Engineering Manual (TEM) and the DriveOhio CV/AV System Engineering Guidebook (ConOps Template).

1.1 System Overview

Bosch Engineering Group (Bosch) is the technology provider for this test. Bosch has developed a truck platooning system using its successful experience with the ENSEMBLE tests in Europe. The platooning solution relies on Bosch-developed advanced driver assistance features including lane centering and adaptive cruise control. Bosch also has a data acquisition and analysis system, which will be used to gather and report data for truck automation performance measurements. The integration team developed this ConOps in close consultation with Bosch staff to ensure an original equipment manufacturer (OEM)-grade system that can be deployed in revenue service.

Bosch follows a rigorous testing program to ensure a safe deployment. The first step in the process is a system test on a closed-course test track at TRC in East Liberty, OH. Following successful track tests, Bosch will conduct a road-release test on public roads, followed by system acceptance testing to ensure that all system components are performing safely and satisfactorily. Only after successful completion of all validation tests will the system be approved for operational pilot testing to collect and analyze data for use by USDOT.

Once the system is validated, pilot testing will occur on public roads. Ideally, single truck and platoon testing would occur in partnership with a yet to be determined fleet partner, but the fleet partner will ultimately decide whether to test platoons in revenue service. If they elect not to, the deployment partners will test the platoon function on suitable routes in southeast Ohio using ballast to simulate loaded trailers. The fleet partner will define test routes and determine drivers and loads in advance for single truck testing and platooning, if applicable. For the platoon feature, following trucks will issue a join request when it is safe to do so, to which the lead truck will respond if it is available for platooning. Upon accepting a join request, the lead truck will begin transmitting platoon control messages (PCMs).

The truck automation system will collect and store performance measurement data for backend transmission to analytical tools for further evaluation and visualization. The operating characteristics and functional and performance requirements, both for operation and data collection, are further described in subsequent sections.

1.2 Referenced Documents

Table 1 shows the documents and literature used for background research, standards, and functional requirements development.

Table 1: References

Document Number	Title	Revision	Publication Date
1362-1998	Institute of Electrical and Electronics Engineers (IEEE). *IEEE Guide for Information Technology – System Definition – Concept of Operations (ConOps) Document.*	1998	March 19, 1998
100124970-3	National Highway Traffic Safety Administration. *Heavy Truck Platooning Systems Hazard Analysis and Risk Assessment – Draft Report*.	1	June 26, 2019
D2.1	Willemsen, D., et al. *Requirements Review from EU projects.* D2.1 of H2020 project ENSEMBLE.	1	September 29, 2018
D2.3	Willemsen, D., et al. *V2 Platooning use cases, scenario definition and Platooning Levels.* D2.3 (Version A) of H2020 project ENSEMBLE, www.platooningensemble.eu.	1	January 27, 2020

Document Number	Title	Revision	Publication Date
D2.4	L. Konstantinopoulou, et al. *Functional specification for white-label truck, D2.4* of H2020 project ENSEMBLE, www.platooningENSEMBLE.eu.	1	February 15, 2019
D2.8	Atanassow, B. and K. Sjöberg. *Platooning protocol definition and Communication strategy.* D2.8 of H2020 project ENSEMBLE, www.platooningensemble.eu.	1	December 19, 2018
D2.9	Atanassow, B. *Security framework for platooning.* D2.9 of H2020 project ENSEMBLE, www.platooningensemble.eu	1	June 11, 2019
n/a	Ohio Department of Transportation. *Traffic Engineering Manual*. Section 13, https://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Documents/TEM%20Part13_071621.pdf	n/a	July 16, 2021
n/a	DriveOhio. *Ohio CV/AV Systems Engineering Guidebook*. Concept of Operations Template, https://drive.ohio.gov/wps/portal/gov/driveohio/about-driveohio/cv-av-systems/tools/04-conops-template	1	June 11, 2020

2.0 Current System or Situation

There is no current 'system,' but highways in Ohio are major freight corridors serving multiple states, and shippers/carriers frequently move multiple loads between similar origins and destinations. Such trip patterns may lend themselves to platooning. Corridors in Ohio that may lend themselves to platooning include Interstate 70, US 33, US 32, and US 35. Even where market forces or infrastructure don't support platooning, rural freight operations may benefit from single truck driver assistance features like lane centering. Moreover, the technologies used for platooning such as forward collision avoidance via radar can improve safety whether trucks are platooning or not.

Truck platooning has been demonstrated in controlled environments and on-road deployments in the US and Europe. Private firms such as Locomation are working to bring platooning technology to market. FHWA is sponsoring a field operational test deploying two- and three-truck platoons via a fleet partner on Interstate 10 from California to Texas. Bosch has tested truck platoons through the ENSEMBLE program in Europe. However, to-date no truck manufacturer has offered a truck platooning solution as original equipment on new tractors.

Freight and logistics firms, transportation agencies, and the public wish to understand the opportunities, risks, and potential benefits of new goods movement technologies. However, there is limited publicly available deployment data for assessing truck automation performance and benefits. Filling this gap is a key ADS program goal.

2.1 Laws and Regulations Governing Platooning

Since truck platooning involves trucks following each other more closely than they normally would, it may require legislation or special exemptions for testing on public roads. Ohio statute doesn't formally define truck platooning or provide exemptions for it from the state's following too closely rule. That rule stipulates a minimum distance of 300 feet for heavy trucks "while ascending to the crest of a grade beyond which the driver's view of a roadway is obstructed."[2] Ohio regulations also require heavy trucks to maintain enough spacing to allow other vehicles to enter and occupy without danger. Hence, a regulatory exemption or special permit from law enforcement agencies may be necessary to enable platooning on public roads.

Ohio is one of several "home rule" states where local jurisdictions exercise governance powers including traffic regulations as they see fit, provided they don't conflict with the state or federal constitutions. This may pose issues for testing since the vehicles will cross jurisdictional boundaries, each with a potentially different regulatory environment.

Ohio has demonstrated support for new transportation technologies with the creation of DriveOhio in 2018. DriveOhio is a forum for researchers, developers, and manufacturers to collaborate on autonomous and connected vehicle initiatives in Ohio. Former governor John R. Kasich signed an executive order on May 9, 2018 authorizing automated vehicle testing and laying out a roadmap for how the automotive industry can test new technologies in the state. The order features a regulatory exemption for automated systems tests in Ohio which allows for testing of such technologies. On

[2] Ohio Revised Code Section 4511.34, Space between moving vehicles.

October 25, 2019, current governor Mike DeWine signed Executive Order 2019-26D reauthorizing DriveOhio and outlined requirements for testing and demonstration in the state.

2.2 Stakeholder Profiles

Stakeholders in the DriveOhio ADS truck automation deployment include many groups who will either use the technology (e.g., truck drivers and fleet staff) or be affected by its use (e.g., law enforcement/first responders and local agencies). Table 2 lists the user classes and their roles in the project.

Table 2: Description of User Classes

User Class	Roles and Responsibilities
Host Fleet Operations Staff	▪ Plan daily work, dispatch trucks to customer locations, execute and manage shipments, inspect/maintain trucks
Truck Drivers	▪ Transport freight between customer origins and destinations, communicate with dispatch staff
Trucking Companies	▪ Advise on technology needs/requirements for the trucking industry; interested in risks and benefits of the technology including cybersecurity, interoperability, and life cycle costs
Warehouses, Distribution Centers, and Distributors	▪ Receive freight shipments, schedule product unloading and local distribution
Infrastructure Owners and Operators	▪ Own and manage road infrastructure, advise on public sector needs for pilot test
Public Safety and Law Enforcement	▪ Enforce traffic laws to ensure safety, respond to incidents
Logistics Industry Organizations	▪ Promote and grow logistics businesses, advise on technology needs/requirements for the logistics sector
Local Government Agencies	▪ Advise on public sector needs with respect to deployment tests, including potential for different regulatory requirements on test routes
USDOT/Federal Motor Carrier Safety Administration	▪ Manage overall grant, analyze project data to inform regulations and rulemaking
Automotive Industry Original Equipment Manufacturers (OEMs)	▪ Interested in automated driving systems trends, safety, and regulations for future business planning
Elected Officials	▪ Interested in overall project results, and implications for policy and economic development within Ohio
DriveOhio and Grant Deployment Team	▪ DriveOhio is the lead agency responsible for delivering the grant in partnership with the deployment team which includes technology providers, test partners, and the consultant integration team
Third Party Researchers	▪ Researchers who are interested in analyzing data from real-world ADS deployments to understand safety and mobility implications
General Public	▪ Other transportation system users who would be interacting with deployment trucks on the road and may be interested in test outcomes

User Class	Roles and Responsibilities
Economic Development Groups	▪ Interested in technology implications for rural economic development
Environmental Groups	▪ Interested in energy and emissions benefits of truck automation technologies

3.0 User Needs

Truck automation may improve freight safety and efficiency, with positive benefits for fleets and society. Hence, it is important to understand stakeholder needs and concerns about the technology. Local community involvement is crucial in Ohio to identify needs and obstacles, and to generate stakeholder buy-in for the deployment test. This section describes the user needs identified for truck automation.

A series of user needs focus groups were held via video conference calls in May and July 2021. These focus groups included USDOT officials, public safety and police in southeast Ohio, local engineering and planning agencies, ODOT staff, trucking and logistics industry representatives, and the Ohio State Highway Patrol. Six focus group meetings were held with a total of 35 attendees. Participants provided feedback on both truck automation and passenger vehicle automation; only user needs relevant for truck automation are included here.

The needs are summarized in Table 3. Most of the needs revolve around safety, the business case for automation, training requirements for fleet staff and law enforcement, public engagement/messaging, data, truck automation operating domain, and interactions with other road users.

Some needs are not part of the deployment test scope. These are marked with an 'N' in the fifth column of Table 3. The 'Notes' column in the table explains why these needs are excluded from the operational test. Exclusion from the deployment test doesn't necessarily mean the need will not be addressed. In many cases, such needs will be addressed through test operational policies or constraints (e.g., conducting a public engagement and communications campaign). In other cases, such as driver recruitment and retention, the ultimate decision authority lies with private firms. One need (Driver Monitoring) is outside the scope of this deployment but is being addressed in separate USDOT truck platooning research.

Needs not directly addressed by this deployment may suggest opportunities for additional data collection (if permitted by available resources). Alternately, they could be explored through future research, including researchers who may access and use the data generated by this test via USDOT databases.

Table 3: User Needs Generated from Focus Groups

Identification	Title	Description	Rationale	Within Test Scope? Y/N	Notes
TRCK-UN001-v01	Business Case for Truck Platooning	Truck platooning needs to have a viable, value-add business case or return on investment to attract fleets.	Required for adoption.	Y	
TRCK-UN002-v01	Platoon Gap	The truck platooning system must identify the traveling distance or time gap between vehicles.	Operators and road users need to know the safe distance between platooning trucks.	Y	
TRCK-UN003-v01	Safety Policy	Truck platooning must consider safety as a high priority when planning and developing truck platooning activities and supporting policies, plans, regulations, education, and infrastructure.	Safety is the number one concern of all stakeholders and operators.	Y	
TRCK-UN004-v01	Monitoring Drivers	Trucking industry needs and desires the ability to monitor platoon drivers.	Safe operations of the system require oversight.	N	Driver monitoring is outside the scope of this deployment. It is also being addressed via other USDOT research.
TRCK-UN005-v01	Truck Maintenance	Need to understand what new skills and responsibilities will be required of truck mechanics and maintenance technicians.	New systems will require maintenance training.	N	Maintenance requirements will be conveyed to the host fleet by TRC prior to field deployment. Training will be delivered via methods defined in the *Driver Training and Qualifications Plan.*
TRCK-UN006-v01	Platoon Operations Time	Need to develop conditions, policies, and procedures to recommend and regulate the amount of time that trucks will be platooned.	Freight operators and agencies need to know how long trucks can operate safely in a platoon.	Y	
TRCK-UN007-v01	Trucking Company Risks	Truck platooning programs will need to include an analysis of potential risks and expected liability for participating trucking companies and other freight stakeholders.	To ensure adoption by trucking companies, risks and liabilities must be analyzed and made clear.	N	Surveys and interviews by the project team may partially address this need, but this decision must ultimately be made by individual fleets. Third party researchers may use test data to estimate these risks.

Identification	Title	Description	Rationale	Within Test Scope? Y/N	Notes
TRCK-UN008-v01	Platooning Data	Need to provide/publish updated data on truck platooning for industry consideration and decision-making.	Data transparency will enable and inform jurisdictional and industry decisions.	Y	
TRCK-UN009-v01	Connectivity	Truck platooning systems need to consider poor cellular network connectivity in rural areas.	If the platooning system requires cloud or cell data/communications, poor connectivity must be addressed.	Y	
TRCK-UN010-v01	Roadway Infrastructure	To encourage adoption, truck platooning programs must consider roadway infrastructure requirements.	Freight operators and agencies need to know infrastructure needs for truck automation.	Y	
TRCK-UN011-v01	Public Awareness	Need to ensure that there is an extensive public awareness program to support truck platooning.	Public awareness of platooning operations will enhance program adoptability and foster public support.	N	A robust public engagement program will be conducted before, during, and after the operational test.
TRCK-UN012-v01	Cross-Fleet Operations	Need to develop policies and procedures for cross-fleet platooning (i.e., platoons composed of trucks with different owners).	This is ultimately a private sector decision; the government cannot force it, but a platooning program would be enhanced if encouraged.	N	This test will only involve platooning between trucks of the same fleet. However, interviews with fleet managers may inform on considerations for cross-fleet platooning.
TRCK-UN013-v01	Platoon Procedures	Truck platooning needs to consider the length of the platoon (number of vehicles).	Platooning operations must determine how many vehicles will travel in a platoon for dispatch and scheduling.	N	Only two-truck platoons will be tested in this deployment for simplicity and safety.
TRCK-UN014-v01	Driver Recruitment and Retention	Truck driver recruitment and retention must be considered when implementing truck platooning programs.	Incentives for the driver may be needed due to competition for drivers and to ensure that trained, skilled drivers are available.	N	The deployment team will train drivers, but recruitment and incentives are a private sector decision. An RFP is under development to identify a host fleet. The team will discuss driver recruitment (if needed) with the host fleet after selection through the RFP process.

Identification	Title	Description	Rationale	Within Test Scope? Y/N	Notes
TRCK-UN015-v01	Integration with Other Modes	Truck platooning needs to integrate with existing traffic and other road users (passenger vehicles, etc.) without adversely affecting that traffic.	Truck platooning must integrate with other roadway users.	Y	
TRCK-UN016-v01	Law Enforcement Training	Law enforcement staff will need training about truck platooning operations for the test and for full implementation.	Law enforcement understanding of the systems is a crucial component.	Y	
TRCK-UN017-v01	Platoon Identifiers	Truck platoons need to have visible identification on the trucks and trailers.	All trucks in platoons need to be clearly identified for law enforcement and other roadway user interactions.	N	Platoons will be marked following guidance from other USDOT tests. Proposed markings will be reviewed and approved by law enforcement agencies.
TRCK-UN018-v01	Traffic Laws and Policies	Truck platooning will need to observe relevant traffic safety regulations and laws. Some laws or policies may need to be adjusted to allow truck platooning.	Platooning operations are new and unique roadway use, which may require new and unique laws or policies.	Y	
TRCK-UN019-v01	Operating Environments	Truck platooning systems need to define the operating environment for platooning including different conditions (e.g., weather) for urban and rural platoons, and where platooning will not be allowed.	Deployment partners and the host fleet need to know where and when platooning is allowed.	N	The truck automation operational design domain will be defined during deployment planning and conveyed to the host fleet during pre-deployment training.
TRCK-UN020-v01	Collision Documentation	If a collision occurs with a platooning-equipped truck, data needs to be available to analyze the root cause of the crash.	Collision data needs to be captured to analyze crash causes.	Y	

Identification	Title	Description	Rationale	Within Test Scope? Y/N	Notes
TRCK-UN021-v01	Roadway Work Zone Operations	Truck platooning systems need to consider operations in work zones, including whether the platoon can stay intact in a work zone and if so, what the driver needs to do.	Safe operations through work zones are required.	N	Platoons will dissolve in work zones.
TRCK-UN022-v01	Driver Training	Truck drivers will need training on proper use of the truck platooning system.	New system and policies will require procedures and skills training.	N	The deployment team will train drivers prior to deployment. Training will be delivered via methods defined in the *Driver Training and Qualifications Plan.*
TRCK-UN023-v01	Roadway Conditions	Need to develop policies and procedures for various roadway congestion, construction, and safety decisions.	Operations in challenging roadway conditions must be safe.	N	Ultimately, the decision to use Advanced Driver Assistance System (ADAS) features will reside with drivers who have been properly trained on system use.

4.0 Truck Automation Concept of Operations

4.1 Project Objectives

The objective of this project is to deploy and evaluate truck automation technologies in real-world operating environments to determine the safety and fleet operating benefits that may occur while providing data to inform future deployments and rulemaking.

The project will develop L2 truck automation technology for deployment in revenue service (i.e., hauling real freight for real customers) with one or more truck fleet partners. Single truck operations will involve a lane centering feature that may be used in conjunction with adaptive cruise control (ACC). This feature will rely on multipurpose cameras to allow for automated lateral (steering) control that will keep the truck in the center of the lane. The cameras will combine vehicle data (speed, yaw rate, and acceleration) with other information (lane boundaries, vehicle trajectory) using a functional logic module to translate these inputs into steering commands.

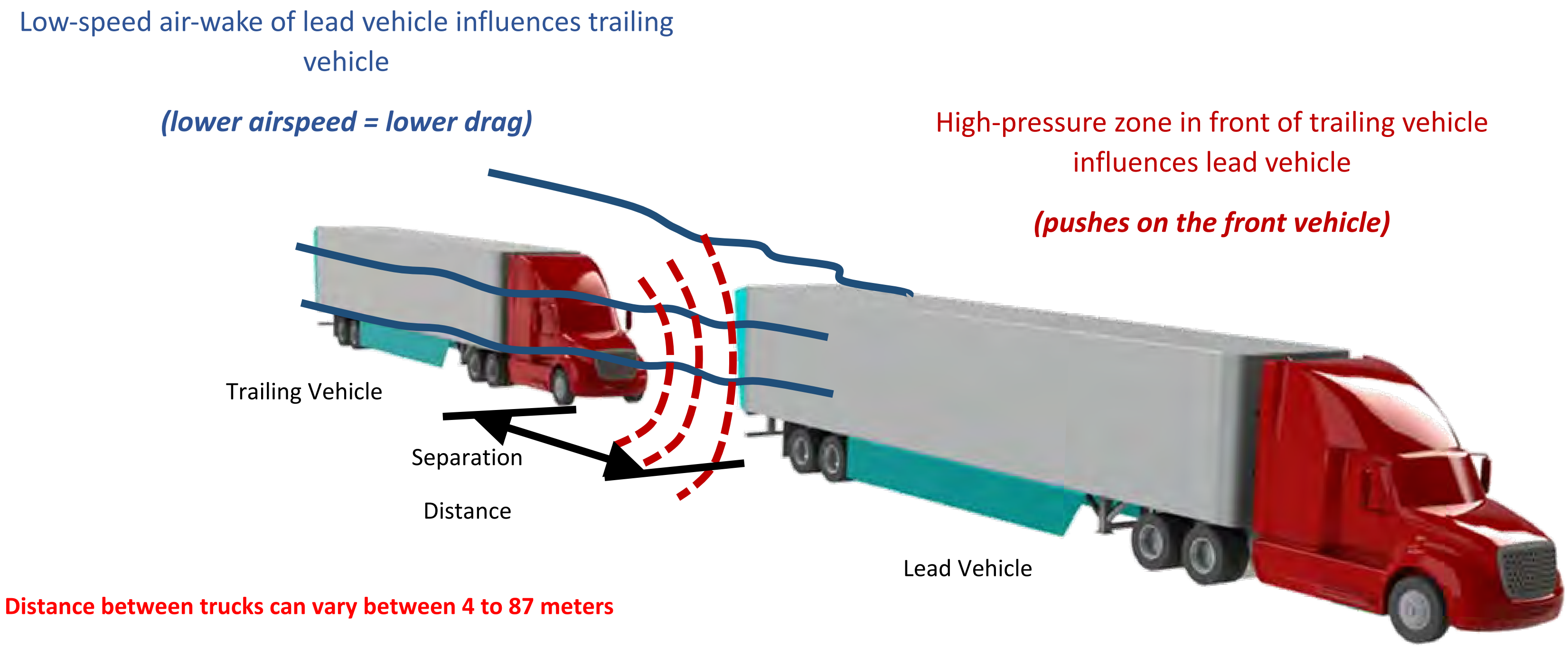
If two trucks are traveling in the same direction on a limited access freeway, they may elect to platoon. Platooning is the practice of electronically "coupling" two or more trucks to allow significantly shorter gaps between them. This technology increases fuel efficiency by reducing aerodynamic drag. The benefits are especially relevant over long distances, where most of a truck's fuel is spent on pushing the truck through the surrounding air. Truck platooning promises reduced congestion, improved safety, and fuel savings to platooning trucks by enabling them to follow each other more closely.

Specific operational details include:

- Platoon operations will involve two-truck platoons, i.e., there would be no more than two trucks in a platoon at any one time. This simplifies testing scenarios and reduces the potential for unsafe interactions with non-platooning traffic.
- Platoons will rely on standard technologies for in-vehicle and vehicle-to-vehicle (V2V) communications (SAE J1939 Controller Area Network [CAN] bus) between two trucks to enable the capabilities required for platoon functions, such as gap maintenance and automatic braking and acceleration.
- The system will rely on radar to identify nearby objects for tracking, including the truck to be followed. A motion control algorithm will determine a target acceleration based on the position and speed of the lead truck; a vehicle control algorithm will decompose the target acceleration into individual commands for engine torque/speed, transmission shifting, braking, and cruise control.
- Lane centering will be decoupled from acceleration and braking control, making it possible to platoon with or without the lane centering feature.

Figure 2 depicts how the platooning system reduces headways between trucks.

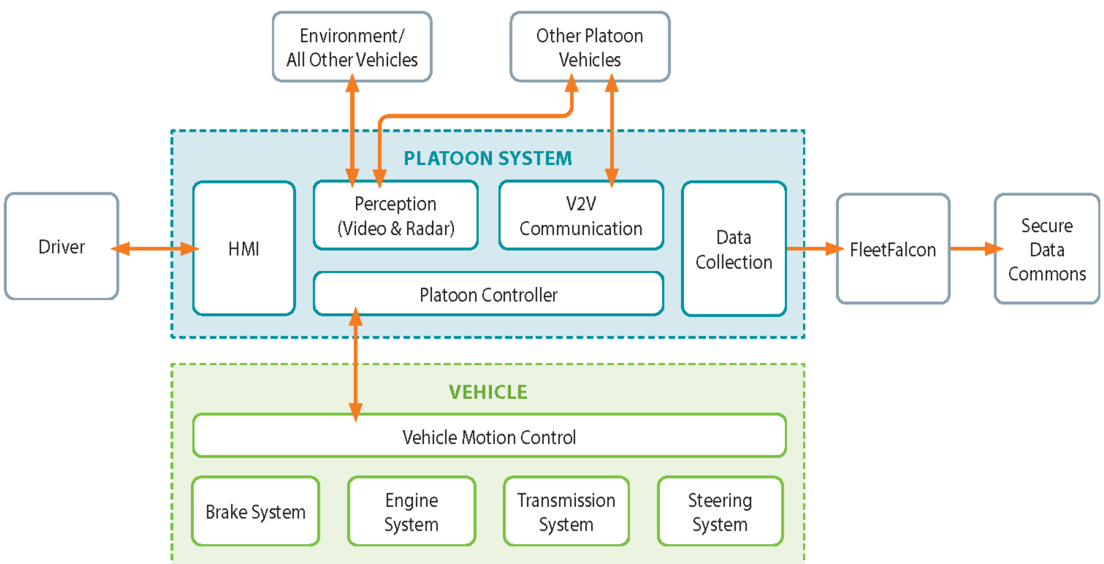
Figure 2: Truck Platooning Conceptual View



The applications to be tested are L1 and L2 driver assist features. At these levels of automation, the driver remains fully engaged in the driving task. Single truck operations will involve a lane centering feature that detects road lane markings with a multifunction camera and uses that information to make steering adjustments such that the truck remains in the center of the travel lane. This feature can be used in conjunction with adaptive cruise control, which uses radar to detect vehicles in front of the truck and adjust the truck's speed as required to maintain a safe following distance. Lane centering, adaptive cruise control, and forward collision warning can operate independently of one another.

The functional diagram in Figure 3 shows the key system components and interfaces. Drivers will interact with the system via a human-machine interface (HMI). The Platoon System controls truck braking, acceleration, and steering (if applicable) using information gathered through sensors including cameras and radar. The Platoon System will also collect data about operations (whether the automated systems are activated or not), which will be sent first to the Bosch FleetFalcon server for initial data processing and thence to the USDOT Secure Data Commons (SDC) for storage and analysis. Additional details about data collection and management are in the *Data Management Plan* provided under separate cover.

Figure 3: Truck Automation Functional Diagram



Source: CDM Smith

The system will have the following features and capabilities, organized by the major blocks in the diagram and described further:

- **Platoon Controller:** The center of the Platoon System in Figure 2. The Platoon Controller processes inputs from other parts of the system and sends commands to the truck's subsystems that automate certain actions or functions.

- **Perception:** Sensors and systems that perceive the truck's position relative to other objects in the environment, including other vehicles. These sensors and systems consist primarily of forward-facing video and radar.
- **V2V Communication:** Facilitates wireless communication between trucks in platoon. This includes communications in all test locations and various weather conditions using cellular vehicle-to-everything (C-V2X) communications.
- **Human Machine Interface:** Means by which the Platoon System interacts with the truck drivers. The HMI will be a device mounted in the cab that will provide information to the driver about platooning status and provide a means for the driver to engage or disengage a platoon.
- **Data Collection:** Collects and disseminates performance measurement data to FleetFalcon and the USDOT SDC.
- **Vehicle Motion Control:** The vehicle system in Figure 2 above interacts with the Platoon System to control acceleration, braking, steering, and transmission.

The system will be able to interface with freight and safety service packages that are delineated in the Ohio Statewide Connected/Automated Vehicle Architecture,[3] including:

- CVO06 Freight Signal Priority
- CVO09 Freight-Specific Dynamic Travel Planning
- CVO10 Road Weather Information for Freight Carriers
- VS01 Autonomous Vehicle Safety Systems
- VS02 V2V Basic Safety
- VS07 Road Weather Motorist Alert and Warning
- VS14 Cooperative Adaptive Cruise Control
- VS16 Automated Vehicle Operations

It may also interface with ODOT Candidate CV/AV application SR-1, Smart Roadside Initiative.[4] The Smart Roadside Initiative is a set of capabilities designed to promote highway safety and efficiency by exchanging commercial vehicle safety and operational data.

[3] Ohio Statewide CV/AV Architecture, Appendix B: Service Package Diagrams. Retrieved August 26, 2021 from https://www.drive.ohio.gov/static/Projects/CV-AV-Guidebook/06-Service%20Package%20Diagrams.pdf.

[4] Ohio Statewide CV/AV Architecture, Appendix A: Ohio CV/AV Applications and Descriptions. Retrieved August 26, 2021 from https://drive.ohio.gov/wps/wcm/connect/gov/64f62760-04b0-472b-89ea-143180962ae3/02-Ohio+Candidate+CV+Applications.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-64f62760-04b0-472b-89ea-143180962ae3-nHyygUc.

While roadside data exchange and V2I are not within the scope of this deployment, such functionalities could be added to the technology via later development and testing projects.

4.2 Operational Policies and Constraints

Several constraints and operational policies were identified for this pilot test. They are divided below into those that apply to both single tractor operations and platooning, and those that apply to truck platooning only.

General Truck Automation

The following constraints and policies apply to all trucks operating in automated mode, either single tractor or in platoon:

1. The driver is ultimately responsible for the L2 automation operational design domain (ODD) and may decide at any time if it is not safe to use the automation features.
2. Driver monitoring via in-cab cameras, eye-tracking technology, and the like is excluded from this deployment test.
3. Drivers will be trained in the proper and safe use of the automation technology.
4. Maintenance requirements for truck automation systems will be communicated to the host fleet prior to field deployment.
5. The deployment team will plan and execute a public communications campaign to raise awareness, answer questions, and foster support for the operational test.
6. Lane centering requires lane markings and shoulder striping/fog lines. The lane centering feature will use a confidence interval to determine if lane markings are sufficient to guide automated steering. If they are not sufficient, the system will alert the driver so the driver can take over all steering responsibilities.
7. The truck automation system will include an HMI that provides situational awareness to the drivers without distractions. The HMI will provide the driver with information about imminent and ongoing system operations and state changes like platoon formation, engage, steady state, speed and gap changes, cut-ins, emergency braking, and system warnings. The system will provide ample warning about any state change that requires the driver to assume control such as lane-keeping system failure, emergency brake situations, or cut-ins.
8. Lane centering (with or without ACC) may operate on lower classification rural routes as well as freeways.
9. Tractors used in the test must be the same make/model and should preferably be the same model year. Different model year trucks may require one truck to always be the designated leader and/or a longer time gap to ensure safety. Such details will be determined during system design and testing.

Truck Platooning

The remaining constraints and policies only apply to trucks in platoon mode:

1. The test needs to consider policies governing platoon planning, formation, and dissolution. These policies will be decided by the host fleet. The host fleet will specify the route(s) for the operational deployment and will need to approve all platoon operational details, including drivers, trucks, and platoon scheduling and dispatch.

2. Platoon operation will need confirmation from affected state DOTs and police regarding any close following rule, platooning laws (if any), truck weight restrictions, bridge restrictions (if any), and any other factors relevant to the operation of platoons in revenue service.

3. The Platoon System will monitor system performance attributes such as brake capacity or radar performance. In the event safe platooning is not possible, the system will be automatically disabled. If conditions are unsafe, platooning will not be enabled. If conditions are unsafe while platooning, the system will dissolve the platoon (with sufficient notice for the driver to resume full control).

4. The deployment test period will follow a system and acceptance test period. The system and acceptance test will be designed to ensure the automation features are safe and operate as intended. TRC will conduct controlled environment and system acceptance testing with multiple trailer load weights and configurations, thus ensuring a safe system for host fleet operational testing.

5. Platoons will only operate on limited access freeways.

6. Trucks involved in the test will not exceed the posted speed limit.

7. Platoons will not operate on roads with curves less than 250 meters in radius.

8. Platoons will not operate in tunnels.

9. The test will stipulate a maximum length of time for trucks to run in platoon mode to mitigate potential driver attentiveness issues. The exact maximum platooning duration will be determined later, during system development and test planning.

10. There may be a maximum gradient beyond which it is unsafe for trucks to platoon. The maximum gradient may differ when trucks are traveling uphill vs. downhill. If the system can no longer maintain the required time gap or the driver decides it is unsafe, the platoon will be dissolved.

11. The test will not deploy L2 platoon automation technologies at night or during inclement weather such as snow, ice, or rain. Other environmental conditions (e.g., sunrise or sunset impacts on sensors) would need to be tested as edge cases.

12. There will be a minimum time gap between platooning trucks. This minimum gap will be determined during system design.

13. Either driver will be able to end a platoon for any reason.

14. The trucks and/or trailers may require special markings to advertise the pilot test and ensure law enforcement and the public are aware of platooning trucks.

15. Platoon operational characteristics such as required time gap may be influenced by the type of brakes on the trailers, which are not always controlled by truck fleets. The platooning technology requires trailers equipped with drum brakes and anti-lock braking systems (ABS). If the trailers used by the host fleet do not have these features, the project may need to acquire appropriate trailers, or the minimum time gap may need to be increased.

16. Platoons may need to dissolve in some road conditions including traffic, work zones, weigh stations, and crashes.

17. The platooning function will not be enabled if the two tractor-trailer combinations differ in weight by more than a pre-determined threshold. An acceptable weight differential will be determined during system validation. Combined vehicle weight will be available via sensors on the tractor-trailer combination.

18. Only trucks from the same fleet will platoon during this test.

19. Only two-truck platoons will be tested in this deployment.

4.3 Assumptions and Challenges

This ConOps relies on the following assumptions:

1. The host fleet will have experienced drivers who will be trained to use the automation system.

2. The host fleet will lease the tractors from TRC and/or Bosch. Lease terms and costs will be determined when a host fleet is selected via request for proposals (RFP).

3. Bosch's driver assist features, platooning, and communications systems will be installed on Navistar trucks that will be leased to the host fleet for use in the test period.

4. The host fleet will provide the USDOT number and other related tractor registration data for leased tractors.

5. The host fleet will integrate the truck automation-capable tractors into their fleet operations during the field operational test. This integration includes tractor insurance, driver rotation, and other operational requirements for a leased tractor being used in host fleet operations. This also includes any pre-trip inspection and regular tractor inspection/maintenance per the host fleet policy.

6. A TRC-trained driver will operate each automation-enabled tractor during the controlled environment and system acceptance test period. A host fleet-trained driver will be in each truck automation-enabled tractor during field operational tests.

7. The host fleet will permit driver surveys and interviews by the project team. The team will work with the host fleet to identify specific data to be collected and shared with USDOT (both confidential and public use). This will be approved as part of human use approval by the Institutional Review Board (IRB) at UC. The fleet and/or the IRB may stipulate limitations on what information can be acquired and published via interviews.
8. Bosch will conduct a system engineering analysis and a risk assessment on the truck automation system. This becomes the basis of a sound and safe deployment system. These analyses will be used for obtaining permission by ODOT and the Ohio State Highway Patrol. These analyses will also be useful for host fleet insurance purposes.
9. The Ohio state police and ODOT will permit trucks in platoon to bypass weigh stations.
10. The State of Ohio will either pass legislation to enable truck platooning or take other action to provide a waiver from the state's following too closely law.
11. Bosch will supply the platoon logic, steering system, and sensor network including radar, video, and vehicle-to-everything (V2X) communication to enable the driver assistance and platooning features.
12. DriveOhio will approve an application for autonomous vehicle testing through the Ohio Autonomous Vehicle Pilot Program. The application will be developed and submitted by TRC (for closed course and initial on-road testing).
13. DriveOhio will approve a separate Autonomous Vehicle Pilot Program application developed and submitted by the selected host fleet.

The following challenges may impact the success of the operational test:

1. **Integrating platoon operation and management controls into the host fleet's logistics management system.** Platoon deployment will ultimately rely on successfully integrating platooning into the host fleet's existing operations. This includes coordination and planning with warehouses and customers on first mile/last mile issues and potential changes in work planning and dispatch procedures. Single truck automation doesn't require this level of integration since it doesn't involve coordinating simultaneous loads and deliveries. Details of integration planning – including approaches to mitigate challenges like cybersecurity, privacy, and interoperability issues – will need to be discussed with the host fleet upon selection.
2. **Finding enough loads with the same origins and destinations to justify platooning.** The integration team expects to work with the host fleet to identify routes with sufficient volume to justify platooning; however, shipment patterns can change quickly, in which case a new route may need to be defined. If a suitable route cannot be found, the project team may need to investigate other ways to collect platooning data.
3. **Obtaining enough operational data to assess the impacts.** Host fleet business imperatives and driver preferences or comfort with the technology will drive system use

during the operational test. This could impact the volume of data collected to support performance measurement.

4. **Keeping up driver interest and cooperation in providing required data and feedback.** Continuous engagement will be required to encourage ongoing participation.

Mitigation strategies for these challenges will be developed when the team creates the forthcoming *Field Environment Test Plan*.

5.0 Use Cases and Operational Scenarios

This section provides a series of use case scenarios that describe how the truck automation system will operate under various modes. Each scenario is a workflow showing steps taken by system users and how the system is expected to respond to different inputs and events.

The following use cases are presented:

- Use Case 1, Scenario 1 (UC1-S1) – Single Truck L1 and L2 Automation
- Use Case 2, Scenario 1 (UC2-S1) – Truck Platoon Formation En Route
- Use Case 2, Scenario 2 (UC2-S2) – Truck Platoon Disengagement En Route
- Use Case 3, Scenario 1 (UC3-S1) – Data Collection and Online Data Storage for Analysis
- Use Case 4, Scenario 1 (UC4-S1) – Platoon System Response without Lateral Control

5.1 Use Case 1, Scenario 1 (UC1-S1) – Single Truck L1 and L2 Automation

<table>
<tr><th>Use Case</th><th colspan="4">Single Truck L1 and L2 Automation</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC1-S1 Single Truck L1 and L2 Automation</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">Host fleet and truck drivers wish to use advanced driver assistance features to improve operations and enhance safety when trucks are not in platoons.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">Host fleet drivers are dispatched on trips that touch one or more deployment test routes and are operating an ADAS-equipped tractor.</td></tr>
<tr><td rowspan="3">Actor(s)</td><th>Actor</th><th colspan="3">Role</th></tr>
<tr><td>Truck Driver</td><td colspan="3">Transport freight between terminals/warehouses and customer locations or distribution centers (DCs)
Maintain communications with dispatcher, particularly if estimated time of arrival (ETA) changes</td></tr>
<tr><td>ADAS Vendor or Partner</td><td colspan="3">Provide ADAS hardware and software
Operate back-end server for data storage and processing
Maintain back-end server
Transfer processed data to SDC</td></tr>
<tr><td>Preconditions</td><td colspan="4">Tractor equipped with adaptive cruise control and lane centering equipment; drivers trained to use system. Tractor is equipped to transmit operating data via C-V2X communications to the Operational Data Environment (ODE).</td></tr>
<tr><td rowspan="2">Key Actions and Flow of Events</td><th>Actor</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>Host Fleet</td><td>1</td><td>The host fleet dispatches an ADAS-equipped truck on a trip that touches a deployment route.</td><td></td></tr>
</table>

Use Case	Single Truck L1 and L2 Automation			
	Truck Driver	2	The driver begins the trip. While operating in rural southeastern Ohio, the driver decides the ADAS features would be beneficial and engages adaptive cruise control (ACC). The truck maintains the cruising speed set by the driver while automatically slowing down to maintain a safe following distance when required (L1 automation).	
	Truck Driver	3	While in ACC mode, the driver decides to turn on the lane centering feature. The truck keeps its lane automatically while remaining in ACC mode (L2 automation). The driver remains alert and supervises the support features.	
	ADAS	4	The ADAS sends data to the back-end server whenever the truck is running, with additional performance measurement data provided when the ADAS features are engaged.	
	ADAS	5a	The ADAS determines it can no longer properly detect the lane markings, so it notifies the driver, who resumes lateral control (L1 automation).	
	Truck Driver	5b	The driver decides that conditions are no longer favorable for lane centering and disengages it (L1 automation).	
	ADAS	6a	The ADAS determines it can no longer maintain a safe following distance, so it notifies the driver, who resumes longitudinal control (L0 automation).	
	Truck Driver	6b	The driver decides that conditions are no longer favorable for ACC and returns to manual (L0) automation.	
Postconditions	Enhanced truck driver experience and safety.			
Policies and Business Rules	None.			
User Needs Traceability	TRCK-UN003-v01 Safety Policy TRCK-UN010-v01 Roadway Infrastructure TRCK-UN020-v01 Collision Documentation			
Inputs Summary	Driver is trained on the tractor ADAS features and supervises tractor operations at all times.			
Output Summary	The ADAS provides the driver with situational awareness and provides performance measurement data to the back-end server.			

5.2 Use Case 2, Scenario 1 (UC2-S1) – Truck Platoon Formation En Route

<table>
<tr><th>Use Case</th><th colspan="4">Truck Platoon Formation En Route</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S1 Truck Platoon Formation En Route</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">Host fleet and truck drivers wish to minimize fuel use and emissions and improve safety with trucks traveling in the same corridor.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">Based on host fleet pre-planning, from which platooning was agreed upon, drivers of properly equipped tractor trailers communicate with each other and gain proximity after entering the limited access highway corridor.</td></tr>
<tr><td rowspan="4">Actor(s)</td><th>Actor</th><th colspan="3">Role</th></tr>
<tr><td>Truck Driver</td><td colspan="3">Transport freight between terminals/warehouses and customer locations or DCs
Maintain communications with dispatcher, particularly if ETA changes</td></tr>
<tr><td>ADAS Vendor or Partner</td><td colspan="3">Provide ADAS hardware and software
Operate back-end server for data storage and processing
Maintain back-end server
Transfer processed data to SDC</td></tr>
<tr><td>Law Enforcement and Public Safety Officials</td><td colspan="3">Maintain awareness of trucks in platoon and monitor operations accordingly (note level of law enforcement involvement will be determined during test planning)</td></tr>
<tr><td>Preconditions</td><td colspan="4">ADAS activated; drivers trained to use system.</td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><th>Actor</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>Host Fleet</td><td>1</td><td>The host fleet determines in advance of the trip that two properly equipped tractor trailers at the same origin traveling in the same corridor should platoon. The lead truck will be designated by the host fleet prior to departure. The host fleet notifies the trained drivers that they should remain in communications and platoon on the limited access highway if conditions permit.</td><td></td></tr>
<tr><td>Host Fleet and Truck Drivers</td><td>2</td><td>Using an appropriate checklist, the host fleet and drivers will perform a complete vehicle inspection, review maintenance logs for the two trucks to platoon, and will test all sensors, the communications system, and the platooning positioning system on each vehicle.</td><td></td></tr>
</table>

Use Case	Truck Platoon Formation En Route			
	Truck Drivers	3	The drivers remain close to each other until they reach the limited access highway, at which point if the traffic conditions and weather are suitable, the following truck driver positions the following vehicle behind the lead vehicle. The lead truck driver will enable platoon active mode using the HMI and then the following driver will issue a join request. Steps 3 through 4 follow ENSEMBLE use case 2.1 'Join from behind.'	
	ADAS	4	The lead truck accepts the join request in the Platoon Management Message (PMM) and platooning begins. The platooning system begins transmitting PCMs. The HMI on each truck provides the driver with the status of the platoon.	
	ADAS	5	The ADAS will maintain a gap between the two trucks based on a default setting derived from prior research and testing. The HMI on each truck provides the driver with the status of the platoon. Upon agreement between the drivers, the gaps can be adjusted by either driver to account for road conditions, weather, or vehicle weight. This step follows ENSEMBLE use case 3.1 'Steady state platooning.'	
	Truck Drivers	6	While platooning, either or both drivers turn on the lane centering feature. The truck keeps its lane automatically while remaining in platooning mode (L2 automation). The driver remains alert and supervises the support features.	Optional step.
	ADAS	7	The ADAS sends performance measurement data to the back-end server.	
	Law Enforcement and Public Safety Officials	8	Law enforcement officials and the public can visually identify platooning tractor trailers and give the vehicles space to continue their platoon.	The project will use emerging guidance from other tests to develop adequate platoon markings. Potentially risky scenarios like cut-ins will be thoroughly tested on the track prior to deployment on public roads.

Use Case	Truck Platoon Formation En Route			
	Lead Driver	9	The lead driver informs the driver of the following truck before approaching any sharp curve, steep uphill or downhill grades, bridges, work zones, accidents, or other events ahead that could affect the platoon or its speed.	Either driver can disengage the platoon if he or she deems it necessary for safety or if required by platoon operational policies.
Postconditions	Fuel consumption and emissions reductions, enhanced truck driver experience and safety.			
Policies and Business Rules	Need a policy on visual identification of the platoon. Need a policy on gap setting and what changes the drivers can make.			
User Needs Traceability	TRCK-UN001-v01 Business Case for Truck Platooning TRCK-UN002-v01 Platoon Gap TRCK-UN003-v01 Safety Policy TRCK-UN006-v01 Platoon Operations Time TRCK-UN008-v01 Platooning Data TRCK-UN016-v01 Law Enforcement Training TRCK-UN018-v01 Traffic Laws and Policies TRCK-UN020-v01 Collision Documentation			
Inputs Summary	Prior to the beginning of the trip, drivers are aware of the plan to platoon on the limited access highway corridor. The following truck initiates a join request.			
Output Summary	The platooning system provides both drivers with system status (speed, gap, etc.) and situational awareness, and provides performance measurement data to the back-end server.			

5.3 Use Case 2, Scenario 2 (UC2-S2) – Truck Platoon Disengagement En Route

Use Case	Truck Platoon Disengagement En Route	
Scenario ID and Title	UC2-S2 Truck Platoon Disengagement En Route	
Scenario Objective	Truck drivers wish to disengage a platoon, or they are required to resume manual control by the ADAS.	
Operational Event(s)	Drivers agree to dissolve an active platoon, or a situation arises that requires such dissolution.	
Actor(s)	**Actor**	**Role**
	Truck Driver	Transport freight between terminals/warehouses and customer locations or DCs Maintain communications with dispatcher, particularly if ETA changes
	ADAS Vendor or Partner	Provide ADAS hardware and software Operate back-end server for data storage and processing Maintain back-end server Transfer processed data to SDC
	Law Enforcement and Public Safety Officials	Maintain awareness of trucks in platoon and monitor operations accordingly
	Non-platooning Motorist	Share the road safely with other traffic, including trucks in platoon
Preconditions	Two trucks in active platoon; drivers trained to use the system.	

Use Case	Truck Platoon Disengagement En Route			
Key Actions and Flow of Events	**Actor**	**Step**	**Key Action**	**Comments**
	Truck Drivers	1	While platooning, drivers stay in touch by voice and by using information provided to them by the host fleet prior to departure.	
	Truck Drivers	2a	Drivers determine when platoon breakup should occur. Either tractor driver may deactivate the platooning system and each driver continues at his or her own pace. This step follows ENSEMBLE use case 4.1.1 'Leaving platoon by trailing truck' and use case 4.1.2 'Leaving platoon by leading truck.'	
	ADAS	2b	The system detects an emergency braking event, automatically begins decelerating within the maximum allowable deceleration, and warns the drivers. The system dissolves the platoon after notifying the drivers via the HMI and safely transferring control. This step follows ENSEMBLE use case 3.3 'Emergency braking.'	The drivers may elect to re-engage the platoon in which case they would follow UC2 S1 above.
	ADAS	2c	The system detects a packet loss or other failure and automatically dissolves the platoon after notifying the drivers via the HMI and safely transferring control. This step follows ENSEMBLE use case 3.4.3 'Warning because of system status (e.g., packet loss).'	This step departs from ENSEMBLE use case 3.4.3 in that the platoon is dissolved rather than automatically adjusting the time gap. The drivers may elect to re-engage the platoon in which case they would follow UC2-S1 above.
	ADAS	2d	The platooning trucks encounter a traffic jam that requires them to stop. The system maintains a safe time/distance gap between the trucks until both trucks are stopped, then dissolves the platoon after notifying the drivers via the HMI and safely transferring control. This step follows ENSEMBLE use case 3.2 'Follow to stop.'	This step departs from ENSEMBLE use case 3.2 in that it doesn't provide an option for automatically re-engaging the platoon. The drivers may elect to re-engage the platoon in which case they would follow UC2-S1 above.
	Truck Driver	2e	The leading driver leaves the platoon (e.g., by exiting the highway or changing lanes) without formally dissolving it. The system detects this event and automatically dissolves the platoon. Each driver is notified via the HMI that the platoon has been dissolved and each continues at his or her own pace. This step follows ENSEMBLE use case 4.3.2 'Leaving by steering out as leading truck.'	This step departs from ENSEMBLE use case 4.3.2 in that it only involves two trucks in platoon and there is no provision for a new platoon configuration.

Use Case	Truck Platoon Disengagement En Route			
	Truck Driver	2f	The trailing driver leaves the platoon (e.g., by exiting the highway or changing lanes) without formally dissolving it. The system detects this event and automatically dissolves the platoon. Each driver is notified via the HMI that the platoon has been dissolved and each continues at his or her own pace. This step follows ENSEMBLE use case 4.3.3 ‘Leaving by steering out as trailing truck.’	This step departs from ENSEMBLE use case 4.3.3 in that it only involves two trucks in platoon and there is no provision for a new platoon configuration.
	Non-platooning Motorist	2g	A motorist driving in the adjacent lane to the platoon cuts in between the lead and following truck. The system detects the cut-in and automatically dissolves the platoon after notifying the drivers via the HMI and safely transferring control. This step follows ENSEMBLE use case 3.4.2 ‘Cut-in.’	This step departs from ENSEMBLE use case 3.4.2 in that the platoon is dissolved rather than automatically adjusting the time gap. The drivers may elect to re-engage the platoon in which case they would follow UC2-S1 above.
	ADAS	3	The ADAS sends performance measurement data to the back-end server.	
Postconditions	Trucks are no longer in platoon; drivers have resumed driving in manual mode.			
Policies and Business Rules	None.			
User Needs Traceability	TRCK-UN001-v01 Business Case for Truck Platooning TRCK-UN002-v01 Platoon Gap TRCK-UN003-v01 Safety Policy TRCK-UN006-v01 Platoon Operations Time TRCK-UN008-v01 Platooning Data TRCK-UN009-v01 Connectivity TRCK-UN010-v01 Roadway Infrastructure TRCK-UN015-v01 Integration with Other Modes TRCK-UN020-v01 Collision Documentation			
Inputs Summary	Either truck driver deactivates the platoon, or the system requires the drivers to resume manual control based on an external event such as a cut-in.			
Output Summary	The ADAS hands off all driving duties to the truck drivers and provides performance measurement data to the back-end server.			

5.4 Use Case 3, Scenario 1 (UC3-S1) – Data Collection and Online Data Storage for Analysis

Use Case	Data Collection and Online Data Storage for Analysis
Scenario ID and Title	UC3-S1 Data Collection and Online Data Storage for Analysis
Scenario Objective	Project test analysts, researchers, and other authorized analysts wish to analyze system performance against predefined performance measures.

<table>
<tr><th>Use Case</th><th colspan="4">Data Collection and Online Data Storage for Analysis</th></tr>
<tr><td>Operational Event(s)</td><td colspan="4">The ADAS-equipped tractors collect operational data during each trip. The data is transmitted to the FleetFalcon server where binary data is converted to formats useful for subsequent performance measurement analysis. The processed data is then transmitted to the USDOT SDC, where it is stored for analysis purposes.</td></tr>
<tr><td rowspan="7">Actor(s)</td><th>Actor</th><th colspan="3">Role</th></tr>
<tr><td>Tractor</td><td colspan="3">Collect truck operating data
Transmit trip stream and event data to FleetFalcon server</td></tr>
<tr><td>ADAS</td><td colspan="3">Collect ADAS truck operations data in accordance with applicable standards
Transmit platoon data to FleetFalcon server</td></tr>
<tr><td>FleetFalcon Server</td><td colspan="3">Operate and maintain back-end server for data storage and processing
Process binary data from truck for subsequent storage and analysis
Validate data from tractor and ADAS
Normalize validated data
Remove personally identifiable information (PII) and confidential business information (CBI) from the data as applicable
Upload data to SDC</td></tr>
<tr><td>Secure Data Commons</td><td colspan="3">Operate and maintain data repository and analysis system for USDOT-related project data
Receive and store data from FleetFalcon
Provide access to authorized users
Provide analysis tools for data analysis</td></tr>
<tr><td>Project Test Analyst</td><td colspan="3">Prepare and implement approved test and evaluation plan
Access data to analyze measures and results of deployment tests
Collect additional qualitative data from drivers and others to support analysis of results</td></tr>
<tr><td>Researcher</td><td colspan="3">Access data to analyze overall impacts of the deployment project on truck platooning
Assess wider impacts of truck platooning on the trucking industry, safety, highway traffic, and the environment</td></tr>
<tr><td>Preconditions</td><td colspan="4">Tractor equipped with ADAS that collects data is operating; communications between tractor and FleetFalcon via the internet; authorized access to SDC.</td></tr>
<tr><td rowspan="6">Key Actions and Flow of Events</td><th>Actor</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>Tractor and Truck Driver</td><td>1</td><td>The ADAS-equipped truck is operating, with or without actively platooning.</td><td></td></tr>
<tr><td>ADAS</td><td>2</td><td>The system collects operational and event data to meet the performance measures.</td><td></td></tr>
<tr><td>ADAS</td><td>3</td><td>The system transmits collected data to the FleetFalcon server.</td><td></td></tr>
<tr><td>FleetFalcon Server</td><td>4</td><td>Data from the ADAS is received, validated, and normalized.
PII and CBI are removed as required.</td><td></td></tr>
<tr><td>Project Test Analyst</td><td>5</td><td>Non-system performance and evaluation data is collected and entered into the FleetFalcon server, including any quantitative and qualitative data that are needed to establish the baseline conditions or assess driver or public impacts.</td><td></td></tr>
</table>

Use Case	Data Collection and Online Data Storage for Analysis			
	FleetFalcon Server	6	Data is uploaded to the SDC.	
	Secure Data Commons	7	Data is received from the FleetFalcon server and loaded into the appropriate project folders.	
	Project Test Analyst	8	Using the Evaluation and Performance Measurement Plan and data in the SDC, the test analyst assesses impacts of the platooning deployment using the defined performance measures.	
	Researcher	9	The researcher uses data in the SDC and the performance measure results to assess wider impacts of truck platooning on the trucking industry, transportation safety, and infrastructure.	
Postconditions	Ultimately, all data approved for dissemination will reside on the SDC. However, some data are collected at different times and are not automatically collected by the truck and platoon system data. Data will be analyzed as needed in the test and evaluation program and by project analysts to support conclusions in the Final Evaluation Report. The SDC data may be used in the future by other analysts looking at truck platooning impacts.			
Policies and Business Rules	The data being collected on the tractors will meet SAE and ENSEMBLE standards wherever possible. Surveys, interviews with drivers, CBI, and PII will be approved in advance by the Institutional Review Board at UC; data will be scrubbed as required prior to delivery to the SDC. Data will be periodically reviewed for accuracy, completeness, and conformance to requirements for analysis of results and support of established performance measures.			
User Needs Traceability	TRCK-UN001-v01 Business Case for Truck Platooning TRCK-UN002-v01 Platoon Gap TRCK-UN003-v01 Safety Policy TRCK-UN006-v01 Platoon Operations Time TRCK-UN008-v01 Platooning Data TRCK-UN009-v01 Connectivity TRCK-UN010-v01 Roadway Infrastructure TRCK-UN015-v01 Integration with Other Modes TRCK-UN016-v01 Law Enforcement Training TRCK-UN018-v01 Traffic Laws and Policies TRCK-UN020-v01 Collision Documentation			
Inputs Summary	The information requirements are defined by the performance measurement and evaluation plan, including attention to the performance measures and in coordination with the independent evaluator.			
Output Summary	Data to assess the performance measures and the overall impacts of the deployment on truck platooning, transportation safety, and the environment.			

5.5 Use Case 4, Scenario 1 (UC4-S1) – Platoon System Response without Lateral Control

<table>
<tr><th>Use Case</th><th colspan="4">Platoon System Response Without Lateral Control</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC4-S1 Platoon System Response Without Lateral Control</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">Host fleet and truck drivers wish to maintain safety when platooning, which may involve evasive maneuvers if an unexpected traffic event occurs nearby the platoon.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">While platooning, two trucks encounter an unexpected event or activity that may require one or both drivers to perform evasive maneuvers.</td></tr>
<tr><td rowspan="5">Actor(s)</td><th>Actor</th><th colspan="3">Role</th></tr>
<tr><td>Truck Driver</td><td colspan="3">Transport freight between terminals/warehouses and customer locations or DCs
Maintain communications with dispatcher, particularly if ETA changes, and with the platoon partner
Coordinate departures, as necessary, with platooning partners
Form platoons when planned and where authorized by the host fleet</td></tr>
<tr><td>ADAS</td><td colspan="3">Provide ADAS hardware and software
Operate back-end server for data storage and processing
Maintain back-end server</td></tr>
<tr><td>Law Enforcement and Public Safety Officials</td><td colspan="3">Maintain awareness of trucks in platoon and monitor operations accordingly</td></tr>
<tr><td>Non-platooning Motorist</td><td colspan="3">Share the road safety with other traffic including trucks in platoon</td></tr>
<tr><td>Preconditions</td><td colspan="4">ADAS activated; drivers trained to use system; two trucks are actively platooning.</td></tr>
<tr><td rowspan="5">Key Actions and Flow of Events</td><th>Actor</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>Non-platooning Motorist</td><td>1</td><td>A motorist driving in the adjacent lane to the platoon performs an abrupt and unexpected maneuver.</td><td>This might also be a pedestrian, an animal, or an object in the roadway.</td></tr>
<tr><td>Following Truck Driver</td><td>2</td><td>If the vehicle or problem in the adjacent lane is nearer to the following truck driver, that driver steers away from danger and then steers back to the appropriate position to continue platooning.</td><td></td></tr>
<tr><td>Lead Truck Driver</td><td>3</td><td>If the vehicle or problem in the adjacent lane is nearer to the lead truck driver, that driver steers away from danger and then steers back to the appropriate position to continue platooning. The following truck driver steers to stay in line with the lead truck, assuming it can be safely done.</td><td></td></tr>
<tr><td>Truck Drivers</td><td>4</td><td>Either tractor driver may decide that continued platooning is unsafe and may dissolve the platoon and each driver continues at his or her own pace.</td><td></td></tr>
</table>

Use Case	Platoon System Response Without Lateral Control			
	ADAS	5	The ADAS detects the two trucks' actions and continues the platoon, temporarily adjusting the distance gap if needed, unless it determines the parameters for safe platoon operation have been exceeded, in which case the system automatically disengages the platoon. The HMI on each truck notifies the drivers that the platoon is being dissolved and they must resume control. In the following vehicle, the ADAS extends the intervehicle time gap until a safe gap for non-platoon driving is restored.	
	Law Enforcement and Public Safety Officials	6	Law enforcement officials and the public can visually identify platooning tractor trailers and give the vehicles space to continue their platoon.	
	ADAS	7	The ADAS sends performance measurement data to the back-end server, including data about the incident and evasive maneuver.	
Postconditions	Normal non-platooning operations if the platoon had to dissolve and drivers did not rejoin.			
Policies and Business Rules	None.			
User Needs Traceability	TRCK-UN001-v01 Business Case for Truck Platooning TRCK-UN002-v01 Platoon Gap TRCK-UN003-v01 Safety Policy TRCK-UN006-v01 Platoon Operations Time TRCK-UN008-v01 Platooning Data TRCK-UN015-v01 Integration with Other Modes TRCK-UN016-v01 Law Enforcement Training TRCK-UN018-v01 Traffic Laws and Policies TRCK-UN020-v01 Collision Documentation			
Inputs Summary	An unexpected event causing either driver to steer to avoid a collision.			
Output Summary	Data to support performance metrics such as number of platoon disengagements/re-engagements, time spent engaged and disengaged from platoon, and locations where platoons engaged/disengaged.			

6.0 Summary of Impacts

New technologies can impact users, stakeholders, government agencies, and the public in many ways. This section summarizes the expected operational and organizational impacts on different stakeholders during system development and deployment.

6.1 Operational Impacts and Benefits

Truck automation deployment for the Ohio ADS project will have the following operational impacts:

- **Potential fleet benefits:** Truck automation may confer operational benefits on the host fleet. Safety is the primary focus of the ADS grant and the chief concern for most fleet operators; hence, much of the performance data the team proposes to collect will support analysis of safety benefits. Other potential benefits include fuel savings via truck platooning, reduced emissions, and improved overall experience or job satisfaction for drivers.

- **Potential fleet risks:** The operational test may collect sensitive PII and/or CBI. Like all web-enabled systems, it may also introduce cybersecurity risks. Privacy and cybersecurity issues will be addressed via the *Data Privacy Plan*, *Data Management Plan*, and through IRB requirements.

- **Changes in load planning/dispatch procedures:** The host fleet will need to plan loads with platooning in mind. This will involve identifying pairs of trucks moving between the same origins and destinations (or at least in the same direction), coordinating warehouse/cross-dock labor requirements with other teams, and notifying the affected drivers of the desire to platoon.

- **Impacts to other vehicles from platoons:** Platoon operations might impact other vehicles on the highway (e.g., during lane changes and merging). However, the platooning technology will adjust platoon spacing or terminate a platoon automatically to deal with traffic conditions, third party vehicle cut-ins, and the like.

- **New interfaces with FleetFalcon and SDC:** The deployment test tractors will require an interface with the Bosch FleetFalcon platform for data ingestion, normalization, and cleansing and then to the SDC for performance measurement reporting. Reporting intervals will be determined during system development. The deployment team will need to consult with the host fleet on these interfaces, including any data privacy and security considerations.

If truck automation technologies are more widely adopted in the future, there may be implications for highway planning and design or maintenance. For example, state DOTs may wish to revisit their maintenance plans if automated trucks aren't able to detect lane markings accurately enough. The deployment test will seek to collect data on the reasons for technology disengagements to assess whether they resulted from infrastructure limitations.

6.2 Organizational Impacts

Host fleet and TRC impacts include:

- **Law enforcement training:** It is important for law enforcement officers to know where and when trucks will be platooning to ensure a safe deployment. Ohio law enforcement staff will need to be trained on how to recognize and interact with platooning trucks before and during the test.

- **Impacts on fleet personnel from interviews:** Drivers, dispatchers, and fleet managers will be interviewed during and after the deployment to help the researchers understand the benefits, risks, limitations, and market readiness of the technology. The host fleet will need to make appropriate staff available for these interviews and will need to participate in any training required by the UC Institutional Review Board.

- **Impacts to fleet maintenance technicians:** Fleet maintenance staff will need to be trained on proper maintenance of truck automation equipment such as collision avoidance, lane centering, and disc brake systems.

- **Retraining requirements for load planners and dispatch staff:** Host fleet staff will require training on how the platooning feature works, and how to identify candidate loads for platooning.

- **Driver training:** Anyone who drives the automation enabled trucks (including TRC test drivers and host fleet drivers) will need training on the proper use of the automation features. Recommended driver training requirements include:

    - Train drivers on the proper use of the total system including how to engage/disengage L1 and L2 features; how to use the HMI and interpret the information it provides; how to form and break off a platoon; maintaining situational awareness; and always supervising the automation features.

    - Recognizing situations outside of the system's ODD (such as work zones, low-visibility conditions, poor weather, heavy traffic, etc.) and refraining from using the features if such conditions exist, or safely disengaging the features when such conditions are encountered.

    - In L1 operation, drivers must be trained to maintain lateral control. In L2 operation, drivers must always keep both hands on the wheel.

- **Potential impacts on host fleet warehouse or customer operations:** Host fleet warehouses or customers may need to adjust staffing levels to accommodate multiple trucks arriving at the same time.

Expected public sector impacts include:

- **Improved data for research, regulation, and rulemaking:** One of the core goals of the ADS grant is to collect data that can support regulation of new technologies and third-party research about their performance. The truck automation safety and operational performance data gathered through this deployment will increase USDOT's knowledge base for its rulemaking efforts. It will also provide anonymized data to the research community for evaluating ADAS benefits and limitations.

- **Stakeholder education requirements:** The outreach workshops revealed a need for public engagement in southeastern Ohio to educate fleets, agencies, and the public about truck automation benefits, risks, and opportunities. This effort must be carried out in coordination with test planning.
- **General public:** The truck automation technologies being tested have the potential to improve safety, air quality, and traffic congestion if they are adopted more widely. While such broad system impacts are difficult to assess in a deployment with just two tractors, the data gleaned from the deployment test can inform additional research and may improve public acceptance of automated driving systems.

6.3 Impacts During Development

During system development, the integration team will need to continue coordinating with Bosch and TRC to ensure the system is fully defined, built, and validated. Bosch will complete the systems engineering and development tasks necessary to specify the system, acquire or develop the necessary components and software, and equip the tractors for the test. TRC will lead system validation at their test facility in East Liberty, OH. This will require reserving track time for controlled environment testing and hiring drivers to complete validation testing.

Once a host fleet is identified, they will need to be involved in meetings to introduce the technology, train drivers and dispatch staff, and integrate the ADAS tractors and data collection procedures into fleet operations. This will be accomplished via software/hardware demonstrations and regular status meetings between the integration team and key host fleet staff.

7.0 Conclusions and Next Steps

This document provides a ConOps for L1 and L2 truck automation deployment in rural southeastern Ohio. The deployment concept supports both single truck automation (adaptive cruise control and lane centering) and truck platooning. The platooning feature will use technology developed by Bosch for the ENSEMBLE project in Europe.

The integration team will use this ConOps to develop system and test functional requirements. The functional requirements will further specify system features, expected behaviors, and deployment test requirements (e.g., human-machine interfaces, data storage procedures, and vehicle identification protocols for platoon operation). Functional requirements will be related to user needs to demonstrate traceability to stakeholder input and ADS program goals.

System development and testing will occur first on a closed test track at TRC, followed by on-road testing near TRC. This stage of testing will use drivers hired and trained by TRC. A yet to be determined fleet partner will then test the system in revenue service on routes they specify. While platooning will only be allowed on limited access freeways outside of urban areas, single truck operations may be tested on appropriate rural roads to better understand how the technology performs on such facilities.

Appendix A lists the performance metrics the team intends to collect during the deployment test. Further details can be found in the *Ohio ADS Project Evaluation and Performance Measurement Plan* provided under separate cover. That document also includes expected data sources and analytical methods to support performance measurement.

Quantitative performance measurement will rely on standard J1939 CAN bus messages coupled with data analytics through the Bosch FleetFalcon platform and routine data transfer to the SDC. Some performance measures will require back-office analysis and interpretation. All fleet data to be released is subject to host fleet approval per their policies regarding CBI and PII.

Qualitative metrics will require surveys and interviews with drivers involved in the test. All such data from drivers will require human use approval from the IRB at UC and will be provided on an as-needed basis to the SDC. Data will be scrubbed of any PII or CBI prior to transferring it to the SDC.

Appendix A: List of Performance Measures and Key Performance Indicators

Performance Measures	Key Performance Indicators (KPIs)
Time-To-Collision (TTC) is defined as the time until a collision between two entities in the scenario environment that would occur if both continue with the present velocities. Violations arise if the measured TTC is below a pre-determined threshold.	Number of times the TTC is below the threshold.
Safety Driver Disengagements (SDD) measure the frequency of instances where the driver of a platooning vehicle disengages Cooperative Automated Cruise Control (CACC). Also, it provides information about the safety and non-safety reasons for such disengagements. Front driver disengages by pressing platoon button. Following driver disengages by pressing brake.	Rate of Driver-Initiated Platoon Disengagements calculated as number of times a driver manually disengages the system per 1,000 miles Reason for disengagement as recorded by driver following the disengagement.
Advanced Driver Assistance System (ADAS) Active for the truck is a confirmation that the adaptive cruise control, cooperative adaptive cruise control, and lane keeping features on the truck are working. CACC working can be called Platoon Usage Rate. This proof can be via vehicle actuation data or some other agreed-upon format.	Ratio of times when ADAS in the truck is active vs. not active. This is an objective metric because the ADAS is either active or inactive while the automation features are running. There are 6 combinations of ADAS Active that can be measured such as Off mode, Adaptive cruise control ACC, Lane Keeping LK, ACC+LK, Cooperative ACC (Platoon), Platooning+LK.
Rules-of-the-Road-Violation (RRV) is defined as an instance of the instrumented vehicle being tested or deployed as programmed violating a traffic regulation that would result in an infraction or citation. The driver observes and responds to the violations. Some violations might cause a disengagement while others will be noted and ignored.	The measure should capture when an RRV occurs and what rule is violated. Potential violations could include lane violations, maximum or minimum speed, traffic signal violations.
Excessive Acceleration (EA) is defined as repeated instances of maneuvers (longitudinal and lateral accelerations) above specified thresholds. This measures the ability of the truck, whether platooning or driving single, to maintain speed and acceleration within acceptable limits for safe operation. In this case, thresholds will need to be created during closed course testing.	Number of longitudinal or lateral acceleration over threshold value for both platooning and non-platooning trucks.
Collision Incident (CI) will capture rates of crashes, near-crashes, and crash-relevant conflicts (including safety-critical events) between the truck and any other vehicle or object.	Rates of crashes, near-crashes, and crash-relevant conflicts between trucks in a platoon or with other vehicles or objects per 1,000 miles traveled.

Performance Measures	Key Performance Indicators (KPIs)
Platooning Gap Compliance (PGC) shows if the time-gap between the vehicles went below a certain value, and if so whether it was due to a trigger event or some other reason. Measure captures the following truck's compliance with the system-defined minimum safe following gap. It measures how the following truck consistently observes the minimum safe following gap under varying conditions such as load and grade.	The number of gap compliance violations per trip and per 1,000 miles at various time gap settings.
V2X communication latency measures the adequacy of communications to and from a truck either in platooning or non-platooning mode. Latency above a particular threshold could be considered a failure.	Number of C-V2X communications failures between each pair of trucks per 1,000 miles driven. Number of times when C-V2X failed to connect at start of platoon trip. Could measure communications in both non-platooning and platooning modes.
Law Enforcement Interaction: This will capture the extent and nature of interactions between truck platoon drivers and law enforcement officials, such as regarding states' safe following distance laws.	Number of law enforcement stops for trucks in platoon compared with typical law enforcement interactions within the host fleet and for the truck in non-platooning mode. Reasons for law enforcement stops for trucks in platoon could be included in surveys and interviews. This is a subjective measure of surveys and interviews with local law enforcement in response to traffic stops. This KPI should deliver minimal data. This traffic stop data will be supplemented by outreach activities for law enforcement that will be documented elsewhere in the project outreach.
Rate of Safety Critical Events: This will measure how often safety critical events occur when ADAS is active and the conditions under which the events occur. It would include an operation by the truck that threatens life or property. This would involve an event trigger and before and after event data reporting.	Total number of crashes between equipped trucks per 1,000 miles. Total number of near crashes (as defined by a couple of time-to-collision threshold values) between equipped trucks per 1,000 miles.
Cut-ins occur when another vehicle enters the space between two platooning trucks. There is a need to understand how often these occur, and the circumstances involved. This is a measure of the frequency of "cut-in" events and durations and circumstances of each cut-in. Under present operating rules, the platoon would disengage when a cut-in occurs.	Number of times a cut-in occurs and number of times a cut-in leads to CACC disengagement per 1,000 miles.
Fleet Operator Acceptance/Satisfaction: This measure seeks to capture information about fleet operators experience with the platooning operation after field testing of the platooning system as well as single mode operation with lane keeping technology. A high acceptance or satisfaction rate of truck platooning technology by fleet operators would be critical to the widespread adoption of truck platooning technology.	A subjective rating of fleet operators' acceptance of or satisfaction with truck platooning and related single mode technology (e.g., on a scale of 1 to 10).

Performance Measures	Key Performance Indicators (KPIs)
Data Quality – Completeness/ Accuracy: This measure looks at whether data collected and stored in the project conveys the same information as the data moves from vehicle to interim storage to final server storage. Quantitative data such as time or distance or location must be the same when viewed on the servers as when collected on the vehicles and retain its accuracy throughout the deployment period.	Conformance of data collected to data model of datasets in the system. Number of missing or incorrect data elements measured at interim server and final storage.
Follower Information: The effectiveness of information provided to drivers of following trucks (e.g., forward video streamed from lead to following truck, other driver-vehicle interface). This involves determining how the following driver uses platooning information in completing his or her driving duties.	Driver perception of platooning performance vs ACC vs regular operation and of the information available during a platoon. Driver perception of Lane Keeping feature compared with non-automated operation.

Appendix A2
Interface Control Document

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30 July 2021

Requirements specification

Recipient DriveOhio
Cc CDM Smith, TRC

Topic **Interface Control Document - Truck Automation**

1 Overview

This document provides a technical description of the public interfaces that will be used for communication between different electronic systems in the Truck Automation part of the DriveOhio ADS Grant project. It describes the technologies used for communication on each interface and the data elements that will be transmitted using those technologies.

This document Is meant to augment the Data Management Plan (DMP) with specific information for software developers, data analysts, and engineers who need to understand, validate, and further develop the deployed systems.

2 Background Information

To understand the data type definitions that are listed later in this document it is important to first understand how data is encoded in the embedded control units in a vehicle. This section will provide some nomenclature and background information that will be used in the protocol and data definitions in later sections.

2.1 Open Systems Interconnection (OSI) Model

Computerized communication generally happens via a system of data encapsulation or layering. Each layer of the protocol will wrap the data from the higher level with the information required to navigate that layer of the protocol stack. Figure 1 provides an example for an HTTP request.

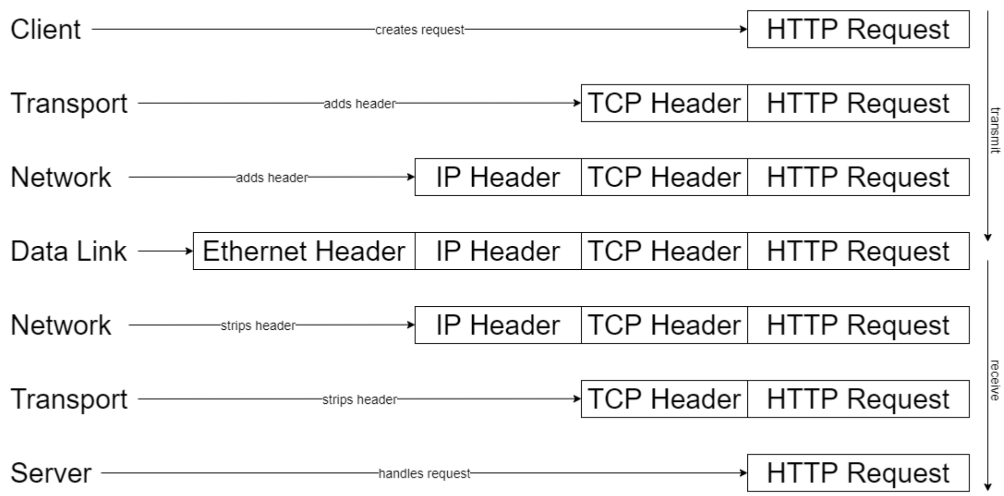

Figure 1 - Example: HTTP Request layering

The standard model for depicting this conceptual layered model is the OSI Model. It defines 7 layers: Application, Presentation, Session, Transport, Network, Data Link, and Physical.

While this is a useful model for comparing different communication stacks, it is important to realize that these are conceptual layers and each stack is different. Most stacks will not have all layers (e.g., the Application, Presentation, and Session are usually all bundled together).

Nevertheless, we will use the OSI Model to provide a high-level conceptual description of each communication interface in the platooning system.

2.2 Fixed-Point Encoding and Conversion Formulas

Embedded control units generally use microcontrollers which have very limited resources in terms of memory and CPU cycles when compared to modern desktop computers. They often do not have a “floating-point unit” which allows for direct calculation of arithmetic with physical values encoded using the IEEE-754 standard.

Instead, automotive control software generally uses “fixed-point” encoding of data where there is a specific conversion formula defined which translates between the “physical” value and the “raw” integer representation used inside the controller.

$$phys = f(raw)$$

While there are many possible formulas that can be used, virtually all signals measurement signals use either a “linear” formula or an “enumeration”.

Using fixed-point also has an advantage in terms of serialization efficiency. There is a fixed relationship between signal precision, range, and required bits for serialization.

2.2.1 Linear formulas

Linear conversion formulas take the following form:

$$phys = raw * Factor + Offset$$

This means that the conversion can be described simply by noting the Factor and Offset values.

Example 1: Encode a percentage in 1 byte:

- Raw: 8 bit unsigned
- Factor: (1/255) * 100 => 0.392
- Offset: 0
- Unit: %

$$phys = raw * 0.392$$

This means we can achieve a precision of 0.392% per bit and we get a range of 0-100% in one byte of data.

Example 2: Encode ambient temperature for a vehicle in 1 byte:

- Raw: 8 bit unsigned
- Factor: 1
- Offset: -40

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- Unit: deg C

$$phys = raw - 40$$

This allows us to have a precision of 1 deg per bit and a range of -40-215 deg C which should cover the relevant ambient temperatures for a vehicle.

Note: this formula would only work for things like ambient or fuel temperature. If we are going to measure catalyst temperature it would quickly go out of range and we would need a different formula.

2.2.2 Enumeration Formulas

Non-numeric data from vehicles is generally encoded using “enumerations.” This includes state and error information, switch or boolean signals, as other notification events.

Enumeration formulas are not mathematical formulas, rather they operate using a pre-defined lookup table. Each possible state is assigned an integer key value, and then the receiver simply looks up the value in the lookup table to understand the physical or textual meaning of the raw data.

Just like with a linear formula there are no wasted bits as we can encode the message with exactly the number of bits that we need to completely describe all the possible states of the signal.

Example 1: Check Engine Light

Raw	Phys
0	MIL off
1	MIL on

Example 2: Automatic Emergency Brake System: Operational State (from J1939)

Raw	Phys

0	system is not ready (initialization not finished)
1	system is temporarily not available (e.g. due to boundary conditions necessary for operation)
2	system is deactivated by driver
3	system is ready and activated (no warning and no braking active)

2.3 Signals and Messages

When electronic systems communicate, they generally send packets which hold several individual pieces of related data. In this document we will use the words Signal and Message to denote these two concepts:

Signal	A single physical value. A conversion formula is always attached to a signal. This is sometimes called a data parameter.
Message	A collection of signals that are transmitted with a single timestamp. This is sometimes called a packet or a sample.

In general, it is possible for a message to have a tree-like structure. In this case the convention in this document is to have a single top-level message definition, and to use “dot” notation to specify the full path of the signal including any containing message structures.

2.4 Interface Description Languages (ASN.1 and Protocol Buffers)

Interface description languages (IDLs) allow for structured definition of communication interfaces. Generally, once an interface has been described using an IDL, a code generator will be used to create serialization and deserialization functionality for translating from in-memory representation to wire format.

This project uses two well-known IDLs. Abstract Syntax Notation One (ASN.1) is broadly used in telecommunications, computer networking, and cryptography. It was first standardized in 1985 and has been updated several times (the latest is ISO 8824 published in 2008). It is used for encoding V2V data. More information is available in the V2V specific sections later in the document.

Google started using a version of protocol buffers in 2001 internally, and open sourced version 2 in 2008. In many ways it is like ASN.1 however it has been greatly simplified for ease of implementation and usage. Protocol buffers are used for binary serialization of data transferred from the vehicle to the ODE and to transmit data from the ODE to the SDC. More details will be in the ODE sections of the documentation.

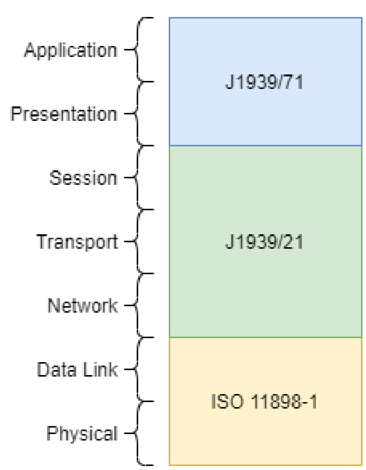
2.5 On-Board Data Logger and MDF4.1

TBD

3 Interface Protocols

This section describes the protocols and serialization/deserialization technologies that are used for transmitting data over the various interfaces. It is concerned only with the data form and sequence, not with the underlying communication technologies and standards.

3.1 Vehicle Data



The primary method for production components in vehicles to communicate with each other is using the CAN 2.0B (ISO 11898-1) bus. Most truck manufacturers use a further standard (SAE J1939) which defines the communication model all the way up to standardized addressing and data definition provided in a Digital Annex.

CAN 2.0B messages can be described using a 29-bit Arbitration ID and up 8 bytes of payload data. J1939 has a special addressing scheme which encodes the Priority, Source Address of the transmitting unit, and the Parameter Group

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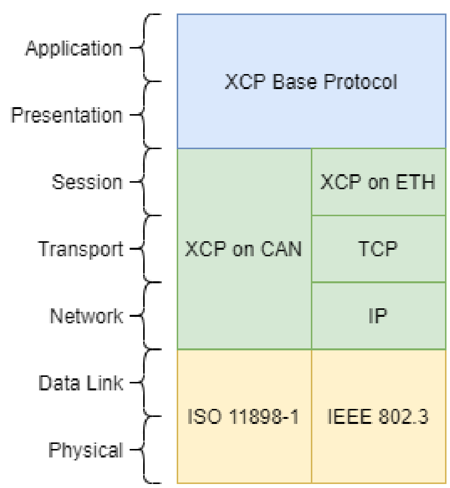
Number (PGN) into the Arbitration ID. The standard then defines several Suspect Parameter Numbers (SPN) for each PGN.

Priority	Parameter Group Number (PGN)	Source Address

The messages defined in the J1939 Digital Annex are transmitted at a cyclical rate and can be read by any device on the bus.

3.2 Instrumentation Data



Development control units generally support collecting more information than would be available on the standard vehicle data CAN bus. They use the ASAM MCD-1 (XCP) Universal Measurement and Calibration Protocol. This protocol allows direct measurement of statically allocated memory inside the controller.

XCP has a standard protocol layer which can be run on top of multiple protocol/physical layers, including CAN, Ethernet, Flexray, USB, and SPI. In our project we will be using XCP on CAN and Ethernet to collect detailed information from the Platoon Controller and the Front Radar.

To use XCP, the measurement device must have a description of the internal structure of the software that is running on the controller. This description is standardized using the ASAM MCD-2 MC (ASAP2 / A2L) Data Model for ECU Measurement and Calibration.

The A2L includes a description including the name, location, size, and conversion formulas for every measurable variable in the ECU.

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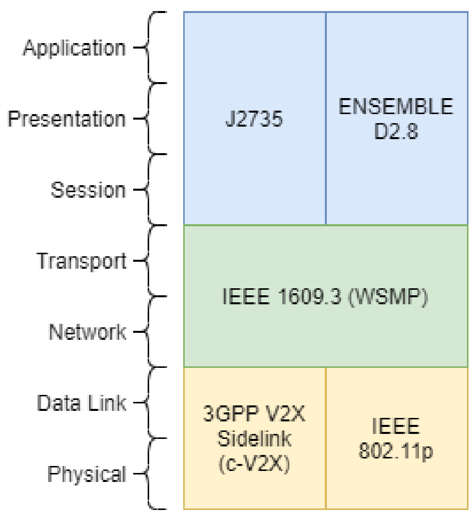
In the case of the Radar and Video unit we will use a secondary “private” CAN bus. It will function the same was as the standard J1939 bus, however it will only be connected to retrofit systems. This allows us to put non-standard messages on the bus without the possibility of conflicting with the production systems.

3.3 Context Video

TBD

3.4 Vehicle-to-Vehicle Communication



The Vehicle-to-Vehicle (V2X) communication stack is used for transmitting data directly between the two platooning vehicles. In the US we are currently transitioning from DSRC (802.11p) to a more modern cellular standard developed by the consortium responsible for defining cellular communication standards (3GPP). We will be using the newer 3GPP standard for communication in this project.

The Network and Transport layers for communication are defined in the IEEE 1609 (WAVE) standard. This standard defines usage of two different Network and Transport protocols. One based on IPv6 and another specifically made for V2V communication called WSMP (WAVE Short Message Protocol). All the V2V communication will use the WSMP protocol.

The WSMP protocol uses an identifier called the PSID to identify the type of data that will be transmitted on the application layer. Since we will be using messages for platooning that have not yet been standardized in the USA, test PSIDs will be used to transmit some communication data. More details can be found with the Data definitions.

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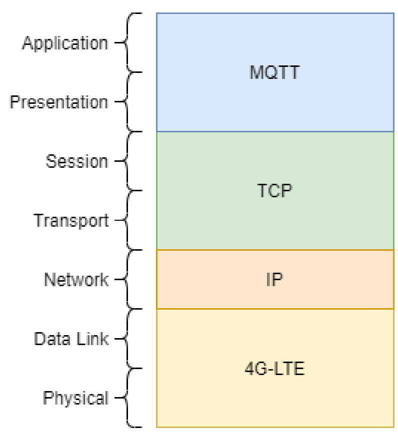
The J2735 standard includes an ASN.1 definition for several application layer messages. In our project the important message is the Basic Safety Message (BSM). This will be transmitted by each platooning vehicle whenever it is on. There is data required for platooning that is not available in the BSM, and so the ENSEMBLE D2.8 publication has created ASN.1 definitions for two more message specifically for platooning: the Platoon Management Message (PMM) and the Platoon Control Message (PCM).

3.5 Vehicle to Operational Data Environment (ODE)



Communication between the vehicle and ODE uses MQTT on top of a cellular internet stack.

MQTT is a publish-subscribe protocol designed specifically for machine-to-machine communication. It allows a hierarchical topic structure with binary payloads.

Data is sent to the ODE using a topic structure as follows:

/fleetfalcon/<device_id>/telemetry/<plugin_id>

The device_id is a unique identifier for each transmitting unit. The plugin_id refers to a unique identifier of the dictionary that defines the decoding rules for the samples that are transmitted on the channel.

The application data is encoded using protocol buffers. The protocol buffer definition does not include the information required to decode the signals in each message.

```
message Sample {
  map<uint64, Message> messages = 1;
  map<string, string> extra_tags = 2;
}

message Message {
  uint64 id = 1;
  bytes data = 2;
  uint64 signal_mask = 3;
}
```

The IDL definition of the base unit of data sent to the ODE is as follows:
The plugin is also stored as a Protocol Buffer, however it stays located in the backend and will not be transmitted. This means that the vehicle does not necessarily have all information required to decode the binary data it is recording.

The structure of the dictionary is as follows:

```
message Dictionary {
  map<uint64, MessageDefinition> messages = 1;
  map<string, Conversion> conversions = 2;
}

message MessageDefinition {
  uint64 id = 1;
  string name = 2;
  repeated SignalDefinition signals = 3;
}

message SignalDefinition {
  string name = 1;
  string description = 2;
  uint32 startBit = 3;
  uint32 bitLength = 4;
  bool bigEndian = 5;
  bool signed = 6;
  string unit = 7;
  string cnv = 8;
}

message Conversion {
  oneof type {
    LinearConversion linear = 1;
    EnumConversion enum = 2;
  }
}

message EnumConversion {
  map<int64, string> values = 1;
  string default = 2;
}

message LinearConversion {
  double offset = 1;
```

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3.6 Operational Data Environment (ODE) to Secure Data Commons (SDC)

The FleetFalcon ODE will use the Dictionary to convert the raw binary data that is reported into a self-describing format that is also modelled using Protocol Buffers. The base data unit for the converted data is a **TaggedSample**. The IDL definition of this as follows:

```
message TaggedTelemetry {
   google.protobuf.Timestamp timestamp = 1;
   repeated ffplugin.TaggedSample samples = 2;
}

message TaggedSample {
   map<string, string> tags = 1;
   map<string, FieldData> fields = 2;
}

message FieldData {
   oneof data {
      double value = 1;
      string message = 2;
   }
   oneof raw {
      uint64 uval = 3;
      sint64 sval = 4;
      bytes byteval = 7;
   }
```

This is modelled to match the structure of a time-series database such as InfluxDB or Prometheus. It could however be used to ingest into any number of standard database forms.

The precise nature of the ingest pipeline and storage in the SDC will be defined later.

4 Data Definitions

This section includes tables with the known message and signal definitions for the different interfaces. While the protocols are varied across the different interfaces, we will generalize to using Messages and Signals as defined in section 2.3.

In order to aid readability, the data definition tables are provided as embedded excel tables.

4.1 Vehicle Data

J1939_Signal_Table.
xlsx

4.2 Instrumentation Data

PrivateCAN_Signal_
Table.xlsx

XCP data from Platoon Controller TBD

4.3 Vehicle-to-Vehicle Communication

TBD

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Version History

Version	Change Log	Author	Date
V0.1	Initial Version	Elliot Morrison-Reed	08/16/2021

BEG/PJ-EDS-NA

Appendix A3
Controlled Environment Report

Truck Platooning Controlled Environment Report

Prepared By:

Transportation Research Center, Inc.

Prepared For:

DriveOhio
The Future of Smart Mobility

01/18/2023

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List of Acronyms, Abbreviations and Symbols

ADS	Automated Driving System
GPS	Global Positioning System
SV	Subject Vehicle
SAE	Society of Automotive Engineers

1 Introduction

The Transportation Research Center Inc. (TRC) has completed the Controlled Environment Testing for the Automated Driving Systems (ADS) Demonstration Grant awarded to DriveOhio-led team by The U.S. Department of Transportation (USDOT). The purpose of the project is to evaluate ADS operation in rural areas. A variety of tests were conducted on an aftermarket platooning system installed in two commercially available tractor-trailers in a controlled-environment to evaluate the viability of deployment on rural roads and demonstrate the viability of the proposed platooning system.

This document provides the reader with:

- A brief overview of the test objectives
- The controlled environment testing

- The conclusions of the controlled environment testing

TRC Inc. has conducted the controlled environment testing at the Transportation Research Center Proving Grounds in East Liberty Ohio, with support from project partners. The results of the testing and evaluation informed the ADS Demonstration Grant team of the operational considerations, necessary procedures, and readiness for deployments and data collection on rural roads.

2 Controlled Environment Testing Objective

There were two primary objectives of controlled environment testing that was performed by TRC Inc.:

1. System education and prove out
2. System behavior extrapolation

The first objective of controlled environment testing was for the testing and research teams of TRC Inc. to educate themselves on the system that was tested and prove out the operational characteristics being tested. For any platooning system that will eventually be tested on public roads, this includes the following sub-objectives:

- Basic systems functionality training and prove out
    - TRC Teams must achieve mastery of the system to ensure that tests can be performed safely, reliably, and repeatedly. This means training test teams on the appropriate systems so that they have an understanding of how to operate the vehicles, as well as expected vehicle behavior across all potential scenarios. Systems and personnel are taken through a wide variety of testing scenarios to prove out systems operations and train the personnel on vehicle operations.
- Data recording development and prove out
    - As a requirement of testing, all data acquisition systems (DAQ) must be developed and deployed in a controlled environment to prove out operation prior to on road deployment. This includes the prove-out of the entire data transmission pipeline up to the point of data storage pending data processing. The platooning system uses cellular communication to upload a wide variety of status and performance measurements to the cloud in Fleet Explorer.
- Limit systems operations
    - It is necessary for test teams to test systems at operational limits. While nearly all public road testing does not occur at operational limits, operational limits can sometimes be reached during road deployments. As a result, it is necessary for test team members to understand where the operational limits are and how the

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vehicle responds prior to operational limits, once operational limits are reached, and as operational limits are exceeded. In particular these limits are important to understand when they may lead to a quick turn over of primary control to the driver.

An inherent limitation of any controlled environment testing is an understanding that only a small portion of the potential operational scenarios will be covered during controlled environment testing. This limitation necessitates that the subset of tests covered during controlled environment testing allow for the extrapolation of vehicle behavior to all scenarios that might be encountered on roadways. This is the second objective to be accomplished, taking the demonstrated behavior seen during the testing and extrapolating to potential failure modes that could be seen on roads.

3 Testing Phase 1 – Fundamentals and Subsystems Testing

3.1 Results

The focus of Phase 1 of the Controlled Environment Testing was to subject the base vehicle's control and braking system to a broad spectrum of tests before the platooning system was activated. These tests were designed to answer questions such as:

- What is the maximum braking that can be expected from the tractor trailers at different speeds and loads?
- Do the longitudinal and lateral controls work when not in platooning?
- What is the performance of the base safety features?
- What is the performance of the initialization and location accuracy needed to maintain an active platoon.

The focus was on understanding the reliability of the base vehicle's features and ensuring the subsystems needed to activate the platooning system were ready. The following subsections outline the categories of tests that were performed.

3.1.1 Initialization Checks

The initialization checks were done to examine the Human-Machine Interface (HMI) implementation, behavior when engaging platooning system (but not forming an active platoon) and other underlying system details. Several notes were taken from this process and ultimately initiated improvements to the HMI. Results from the first set of testing include:

- No sudden acceleration or deceleration if the platooning system was activated, whether the trucks were in position or not.

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- Fleet explorer adequately collects data for monitoring and trouble shooting.
- Platooning lights are too dim but appropriately turn on.
- Error icons available once platooning system is engaged, even if not active.
- System allows for each vehicle to **engage** platooning system without other vehicle nearby. The truck will automatically search and initiate platooning when all parameters are met (lead truck in position in front of follow truck, within 5s following distance, and follow truck above 38-40mph), which will be called **active** platooning.
    - This allows drivers to set system well ahead of time, then focus on driving.
    - However, it also allows activation before the system is actually ready, which resulted in overshoot and undershoot of following truck. It is better to only engage both vehicles when their speeds are well harmonized.
- No ability to know the platooning system settings before activation.
- No read out on status of platooning system health or viability of engagement.

These notes led to several changes to the platooning system HMI. After further testing, the following remedies were implemented:

- There is now a status indicator that displays if the platooning system is ready to be activated. This was aimed at helping the driver engage only when the system is well harmonized to remove overshoot/undershoot from the following truck.
- The following distance can now be read out and changed before engaging/activating the platooning system.

The health of the platooning system is still not available in a concise location to the driver and may cause the vehicle or a specific system to need to be restarted before the platooning system can become activated. In addition, only visual alerts are available. There are no auditory alerts available when the system disengages or other errors occur.

3.1.2 Braking

The lead truck's brakes were tested to understand the maximum performance of the truck with the weaker brakes. In a worst-case scenario, this is the braking that the follow truck would need to maintain in order to prevent a crash with the lead truck. The average deceleration for a full manual brake is given in Table 1. Three loads were used to understand how weight would affect performance of the braking and better understand the worst conditions. Table 2 gives the peak values reached. Overall, the braking is 0.65g, except for the half load where the performance is 0.56g. The offset load (max weight over the rear axle causing bouncing at the drive axles), which was anticipated to be the worst case, ended up performing comparably with the full and empty load. These tests were done as an informative step to inform the time-gap settings if they need to be changed. For example, based on a braking of 0.7g, it takes about 3.5s to stop the lead truck.

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Given a 0.5s reaction time, this will require the follow truck to brake at least -0.56g to stop in time at 55mph.

Table 1. Average deceleration at two speeds in four loading configurations with full manual brake.

Average Deceleration (g)	Empty	Half load	Full load	Offset load
45 mph	0.66	0.56	0.64	0.66
65 mph	0.56	0.45	0.44	0.65

Table 2. Peak deceleration achieved at full braking.

Peak Deceleration (g)	Empty	Half load	Full load	Offset load
45 mph	0.78	0.79	0.81	0.85
65 mph	0.8	0.77	0.78	0.79

NOTE: A 6^{th} order of butterworth filter (N) is considered for the calculation of the peak values, with a cut-off frequency (fc) filter of 3 and a frequency signal (fs) of 100.

3.1.3 Location Accuracy

Location accuracy was tested in three categories: lateral (need to be in the same lane), longitudinal (lead-follow truck in order without a cut-in vehicle), and sensor-GPS agreement. During testing, it was confirmed that platooning would not go from engaged to active:

- Without the vehicles being in the same lane.
- In the correct order with no vehicle in between.
- GNSS on and functioning.
- V2X communication working to provide radar-GNSS agreement demonstrating there was no cut-in vehicle.

However, it was also observed that GNSS could drop during active platooning and the system would not disengage. A vehicle can also cut-in, which does not disengage the system, but rather switches to ACC at a longer following distance of the new car. Once the vehicle exits, the platooning will resume, if within platooning speed and distance parameters.

3.1.4 Lane Keeping

The Lane Keep Assistance System (LKAS) was tested in the original version of the vehicle. Testing showed that the system had unacceptable performance under three different conditions. First, if both lane lines were not dashed the vehicle would not activate LKAS. This is a major operational barrier as most trucks operate in lanes with one dashed and one solid line. Second, relatively low wind speeds of greater than 12 mph would kick the vehicle out of the lane. This speed of wind is common in the area and would greatly reduce data collected with the system engaged and could lead the vehicle suddenly exiting a lane if the driver was not providing correct supervision. Finally, the system was tested in a variety of curves and would disengage or fail to stay within the lane

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in all curves with a radius less than 0.46 miles. Curve radii tested include: 0.12, 0.15, 0.30, and 0.46 miles. In the largest radius curve, LKAS was not always stable.

The system is currently disabled after several attempts to better calibrate the steering failed.

3.1.5 AEB

Testing for the Automatic Emergency Braking (AEB) in the red following (Tom) was done to understand brake performance in the worst case scenario that the driver did not reengage during a braking of the lead vehicle and failure of the platoon software. This testing pairs with the brake testing and seeks to understand the difference in maximum braking between the lead and following vehicles. Two iterations of this testing were done due to a failure mode in the original software causing AEB to become disengaged. This prompted changes to the ACC-CMBS module in the following truck, requiring a retest of the system. Due to the minor scale of the change, it was decided that not all tests needed to be repeated, electing to simplify the testing matrix to a single load and three speed profiles.

3.1.5.1 Initial round of runs

The first set of runs was done at 50mph with a static target as it was the goal to understand the performance of the system at highway speeds. However, it was determined that the native Bendix system is not designed to respond to this speed differential. Instead, a 15 mph run was conducted and if it was successful three more runs at 20 mph were conducted at four different loading configurations. These load configurations were the same as brake testing: empty, half, full, and offset. The results are presented in Table 3. The AEB was also completed with a moving target, shown in Table 4.

From a high level, the AEB either stopped successfully or did not activate the brakes and would either hit or require manual intervention. When the AEB activated, an audible alert (forward collision warning) went off with a series of beeps. When the AEB failed to activate the brakes, an audible alert of only one or two beeps would occur. One deviation from standardized test plans in the initial static target tests is that the driver’s left their foot on throttle after forward collision warning.

Table 3. Static Target

Hit Rate SV Speed (mph)	Empty	Half	Full	Offset
15	1/2		1/1	1/1
20	2/3		2/4	2/3
50	-	-	-	0

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Table 4. Moving target with empty trailer.

SV Speed-Target Speed-Lead decel (kph-kph-g)	Number of hits/runs	Notes
40-15-0	0/3	
75-35-0	0/3	
40-40-0.3	1/3	On impacted run, braking occurred and brought vehicle to coast on impact
55-55-0.3	3/3	

The truck's deceleration varied with the loading configuration. As seen in the chart below, the offset lowest deceleration at -3.6 m/s^2, full averaged -4.0 m/s^2, and empty averaged -4.9 m/s^2. The starting criteria was for the deceleration to reach -0.75 m/s^2, and the end of measurement was when the vehicle reached 0.75 mph. Two runs from each loading configuration successfully stopped without impact and were analyzed. The results are shown in Table 5.

Table 5. Average deceleration during automatic braking event.

Average Deceleration (m/s^2)	Run 1	Run 2	Average
Offset	-3.6	-3.5	-3.6
Full	-3.8	-4.1	-4.0
Empty	-4.4	-5.3	-4.9

Steel trench plate testing was done to test false positive activation of AEB. Three runs were completed with the empty trailer at 25 mph and 45 mph. All runs provided no alerts.

Pedestrian testing was done in the unlikely event that this situation occurred on the highway. After three runs at 15 mph with no alerts or activations, it was determined this was not a capability of the system. For each run, manual intervention was done to prevent damage to the target.

3.1.5.2 Second round of runs

A second round of testing was completed after changes were applied to how the AEB system interacts with the platooning system. A reduced set of test runs were completed due to the low probability of a negative interaction. The changes appeared to improve the AEB performance with no hits recorded, as shown in Table 6. Similar braking was experienced when the system activated in prior tests.

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Table 6. Round 2 AEB Testing

SV Speed-Target Speed-Lead decel (kph-kph-g)	Number of hits/runs
40-0-0	0/3
75-35-0	0/3
40-40-0.3	0/3

3.1.6 Adaptive Cruise Control

This test examined each truck's ability to use the stock Adaptive Cruise Control (ACC) system. The ACC was set to 45 and 65 mph, with the lead vehicle traveling nominally at that constant speed. Once steady state following was achieved, the lead vehicle slowed down 10 mph to determine the response of the following truck. The following truck was able to stabilize the speed and follow at an appropriate distance for the technology (note, no vehicle-to-vehicle V2V communication is used for this interaction). The vehicles maintained at least a 1.5 s headway after the lead vehicle slowed down.

Table 7. ACC following characteristics.

	Speed Change	Max Speed Difference (m/s^2)	Min Distance (m)
Red Truck	45mph to 35mph	2.18	29.12
	65mph to 55mph	3.17	67.69
White Truck	45mph to 35mph	3.80	28.05
	65mph to 55mph	3.39	67.34

4 Testing Phase 2 – Platooning

4.1 Results

The focus of Phase 2 of the Controlled Environment Testing was to subject the platooning system to a focused set of full-system functionality tests. In this phase, the tests were designed to answer questions such as:

- Can the vehicle repeatably activate and deactivate the platooning system as expected?
- Is the platooning system able to stay engaged for prolonged periods?
- How does the following truck behave when platooning is active and a vehicle cuts in?

Through these tests, the TRC Team was able to develop an understanding of feature capabilities and evaluate nominal behavior of the stack.

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4.1.1 Engaging Platooning

Platooning was conducted at 25, 55, and 65 mph. The following distance was set to either 1.4 or 2.0 s. In addition, some tests were conducted on a curve and with another vehicle in between the trucks, to see if this would affect the activation of the platoon. The platoon was allowed to reach steady state before disengaging and beginning another run.

After the initial round of testing, the truck activated the platooning and maintained stable control of the vehicle in all cases, except where an ACC-CMBS error was created by the truck. This was not frequent, but was later identified as a critical issue in the continuous platooning testing.

With the change in HMI and software settings, these disengagements were conducted again and only one change was observed. On the lead vehicle, there was a perpetual radar GPS mismatch error, which may be the result of software changes to the HMI and made it more similar to the follow vehicle.

4.1.2 Disengaging Platooning

The platooning system was tested to ensure the platoon would deactivate as expected under the following conditions:

- Disengage on Lead request
- Disengage with Follow request
- Disengage with brake
- Disengage with Lead change of lane
- Disengage with Follow change of lane
- Disengage with cut-in
- Disengage without comms
- Cut-in with hard deceleration

After the initial round of testing, the truck deactivated with all but the cut in condition. When a vehicle cut in, the truck started to follow the vehicle's speed at a greater distance with platooning still active. After discussion with Bosch, this was a feature that was able to be included and aimed to better hand off control to the driver without an abrupt hand over.

With the change in HMI and software settings, the above disengagements were completed again. When the following truck was not close enough to the lead truck, it self-disengaged without the request being expressly sent from the driver, as expected. In a later run, an unexpected hard braking event occurred without known causation, after the platoon disengaged. There was a very brief error that popped up but did not exist for long enough to discern what it was saying. It was potentially a collision mitigation, but there was no collision to be mitigated, or situation that the humans could tell would be mistaken as one. This should be reviewed but is considered non-

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critical as it seemed to stem from the manufacturer system as the platooning system was not engaged.

The cut-in did not disengage the system, as expected with the current software implementation. Instead, the following truck slowed to follow the cut-in vehicle at around 3s. On one of the cut-ins with deceleration, the event engaged AEB style braking, despite the cut-in vehicle's deceleration being similar to the other runs. It is likely to have been a result of a closer cut-in as the other runs did not get below a headway of 0.4s, but in this run the braking activated at 0.32s. In this run the active platooning system did not override or impede the AEB system. The analysis of the deceleration of the cut-in vehicle and the following truck is shown in Figure 1.

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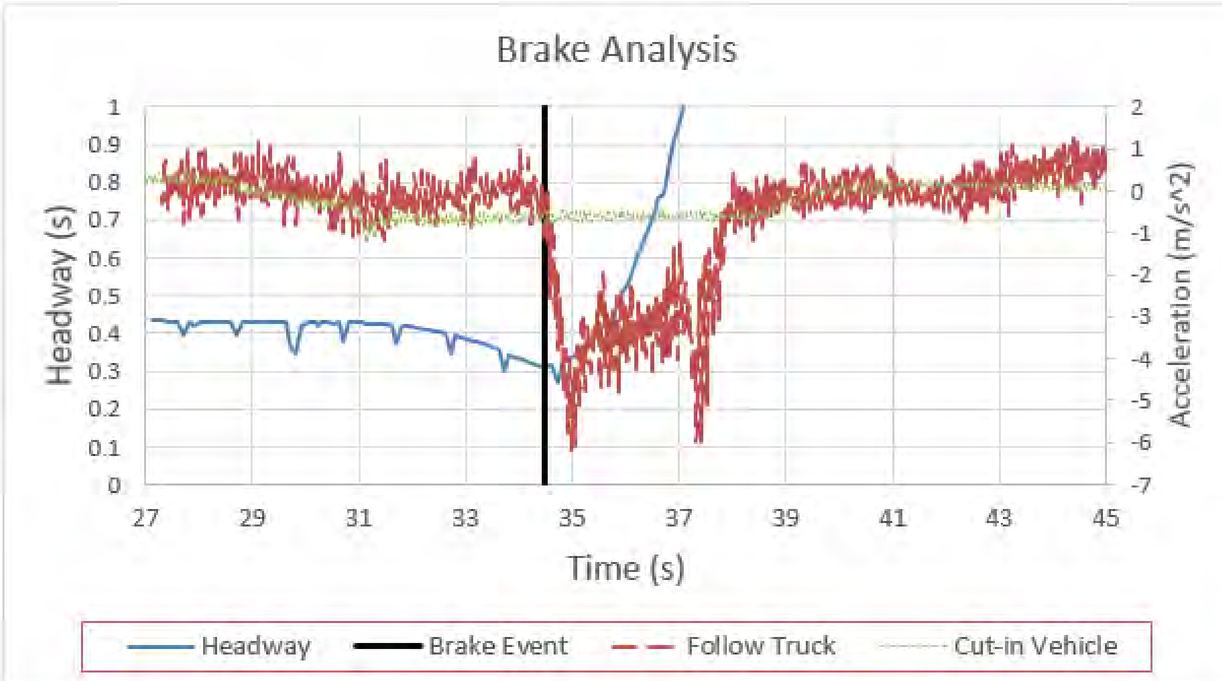

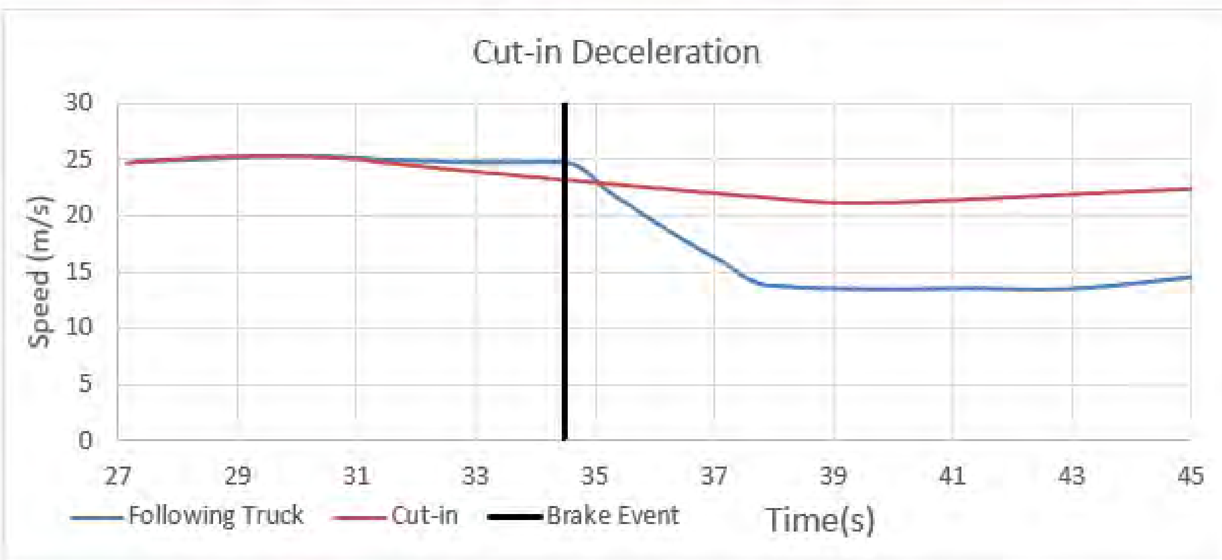

Figure 1. Deceleration analysis after cut-in vehicle brakes.

For the other runs, except when the truck driver applied brake, the platooning system remained active for more than 8s. A lane change led to disengagement of 14s consistently, regardless of which vehicle changed lanes. Disengaging with driver request (via HMI) resulted in the platoon deactivating in 13-25s. These variations in time to disengage were higher than the 8s informed by the Bosch team. However, in these cases, the truck appeared to continue to observe soundings and provide appropriate speed control. When the following truck driver applied the brake, the

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disengagement time was immediate. When the lead truck driver applied the brake, the platooning system remained active.

4.1.3 Continuous Platooning

The continuous platooning test sought to demonstrate the platooning system could sustain a platoon for prolonged periods of time. This test was broken up into 45-60 min long runs at three weight configurations (empty, half, and full), with 3 runs each. A speed profile was followed, but minor changes were made to remove areas outside of the platooning systems operation once this was confirmed. Figure 1 shows the final speed profile used. All tests were done with a following distance of 1.4s. Several speed drops were done below the system cut-off of 40mph.

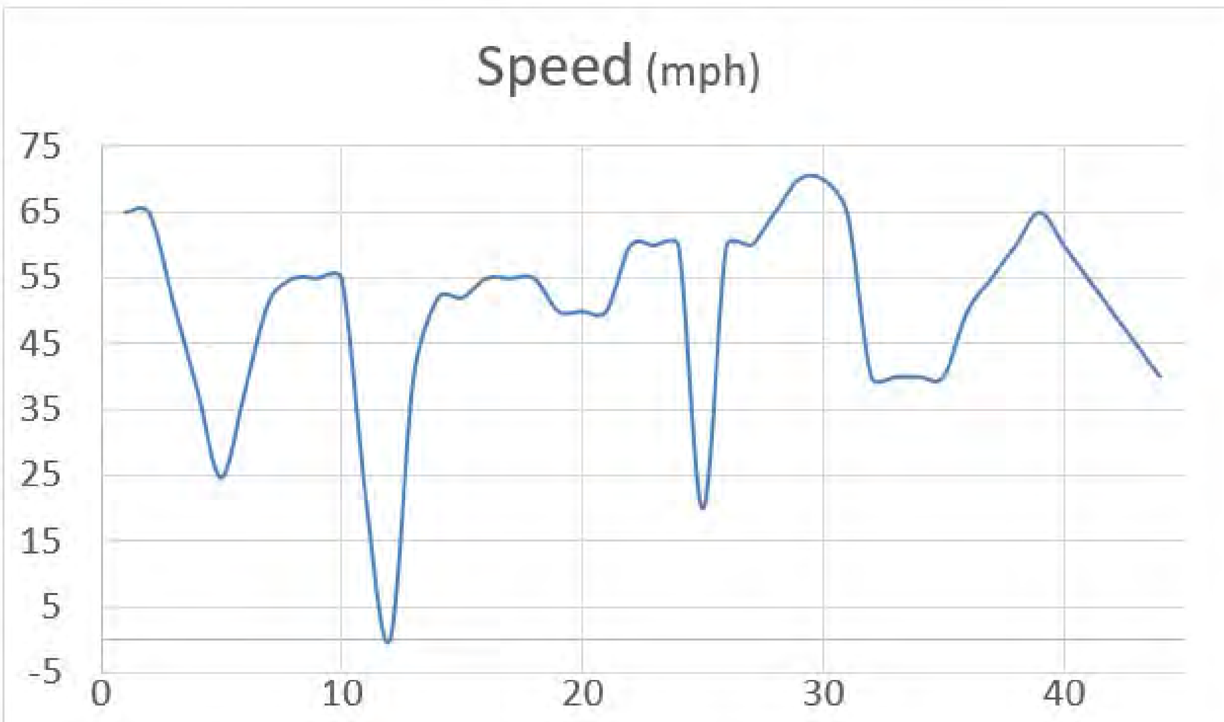

Figure 2. Speed profile used for continuous platooning.

4.1.3.1 Initial round of runs

In the first wave of testing, several critical problems were discovered limiting the platooning system to stay active. This included an ACC-CMBS which disabled AEB, several disengagements, and times where the platooning system failed to activate. After these results, testing was stopped to address these problems and led to the second round of test runs.

4.1.3.2 Second round of runs

The trucks stayed in platoon mode for a large part of the run. There were a few random disengagements at various speeds. When the trucks disengaged due to speed, they only

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reengage platooning if the following truck's speed went above 40 mph, as set in the system's parameters. Lane departure warning was falsely activated for one run, when it seemed that the truck mis-identified a seam line as a lane line. The weight of the truck was 33,500 lbs., 42,930 lbs. and 60,320 lbs. for empty, half, and full loads respectively. The following distance stayed stable during steady state platooning and did not present with any problems even during speed changes.

5 Test Requirements

Testing requirements to each test were defined in the Controlled Environment Test Plan published prior to Controlled Environment Testing. The tests were completed in fair weather conditions defined by:

- Temperatures ranging from 32°F and 80°F.
- Wind not exceeding 25 mph (11.2 m/s).
- High visibility during daylight operating hours.
- There was no testing during inclement weather.

Additionally, testing was completed under ideal roadway conditions with:

- Well-defined lane markings.
- Lane widths between 3.35 to 4.57 m (11.0 to 15.0 ft).
- Well-defined roadway edge.
- Strike-able targets that were easily visible.
- Manually driven roadway traffic that was easily visible.
- Generally, no roadway visibility obstructions.

An overview of the instrumentation used for the tests described in this document is provided in Table 8.

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Table 8. Test Equipment

Type	Output	Range	Accuracy
Tire Pressure Gauge	Vehicle Tire Pressure	0-150 psi	±0.5% of applied pressure
Platform Scales	Vehicle Total, Wheel, and Axle Load	0-20000 lb per each axle	±1.0% of applied load
GPS Speed Sensor[1]	SV and ME(s) speed	0.1-80 mph (0-35.8 m/s)	+/- 0.25% of full scale range
Multi-Axis Inertia Measurement Unit	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm
	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%
Data Acquisition System [Amplify, Anti-Alias, and Digitize]	Record Time; Velocity; Distance; Lateral, Longitudinal, and Vertical Accelerations; Roll, Yaw, and Pitch Rates; Steering Wheel Angle.	Sufficient to meet or exceed individual sensors	Sufficient to meet or exceed individual sensors
Vehicle Dimensional Measurements	Location of GPS antennas; Vehicles Polygon measurements.	N/A	0.04 in (1 mm)
Real-Time calculation of position and velocity relative to lane and Emb	Distance and Velocity to lane and Emb	Lat Lane Dist: ±30 m	±2 cm
		Lat Lane Vel: ±20 m/sec	±0.02 m/sec
		Long Range to Emb: ±200 m	±3 cm
		Long Range Rate: ±50 m/sec	±0.02 m/sec
Robotic Platform with Multi-Axis Inertia Measurement Unit	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm
	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%

[1]Differentially corrected GPS should be used

6 Testing Conclusions

The testing for the platooning system was able to be completed. The initial round of testing discovered critical problems that were addressed with software update. After new software integrations, a second, reduced round of testing was completed. Overall, the final platooning system performed as expected with few non-critical exceptions and a braking issue that needs further discussion. There is still an error being displayed on the lead vehicle that also need to be resolved. As this is an SAE level 1 system, it is imperative that both truck drivers are continuously attentive to the driving task. Table 9 and Table 10 provides a summary of the testing completed and results for the tests.

Table 9. Phase 1 Testing Completed with Trucks

Phase 1	Initial Round	Second Round
System check	Complete	Complete
Braking	Complete	N/A
Location Accuracy		
LKAS	Exited lane	N/A
LKAS - Tight Curve	Exited lane	N/A
AEB Static Pedestrian	Impact	N/A
AEB Static Car	Impact 1/3	No impact
AEB Moving Car	Impact 1/3	No impact
AEB Steel Trench Plate	No alert	N/A
ACC	Adjusted speed	Adjusted speed

*Fewer runs

Table 10. Phase 2 Testing Completed with Trucks

Phase 2	Initial Round	Second Round
Platoon Formation Various Speeds	Engaged	Engaged
Platoon Formation on Curve	Engaged	Engaged
Platoon Formation with Cut in	Did not engage	Did not engage
Disengagement on Request	Disengaged	Disengaged
Disengagement with Brake	Disengaged	Disengaged
Disengagement with Lane Change	Disengaged	Disengaged
Disengagement with Cut-In	Decelerated	Decelerated
Disengagement without Communication	Disengaged	Disengaged
Disengagement with Decel Cut-In	Decelerate then Disengaged	Decelerate then Disengaged
Continuous Platooning	Did not stay engaged	Stayed engaged for majority

Non-critical events experienced during the second round of testing or that were not confirmed to be resolved after first round:

- The lead vehicle has a perpetual radar/GPS mismatch error on HMI.

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- There is no method to check the overall health of the platooning system until on road attempting to platoon. This led to time being wasted while we went and reset the vehicle's systems. In the field this will likely lead to lost data instead.
- A sudden braking event did occur, seemingly like AEB, but without reason. It did not appear to be associated with the platooning system but caused a potentially dangerous situation.
- The following vehicle switches to ACC following, with platooning still engaged, during cut-ins. This was not originally part of the operation plan and was included because it was available. Extensive testing was not done on this feature, but it worked in the limited cases run.
- During the initial round of testing the following truck's AEB failed to activate for a static vehicle target 1 out of 3 runs and the pedestrian 3 out of 3 runs. It is recommended that the platooning system be disengaged if the trucks encounter pedestrians. The AEB activation is also not a part of the platooning system. When some of the conflicts between the AEB and platooning system were resolved, this did seem to improve performance. It should be noted that fewer runs were completed in the second round, as this was not seen as critical in the first place and there was limited risk of the change degrading performance of AEB.
- During the initial round of testing, the following truck's AEB failed to brake sufficiently for a lead vehicle target, decelerating from 34mph at 0.3g on the three test runs. Other moving target tests resulted in successful braking (8 out of 9 trials). Because the platooning is separate from the AEB system, this is seen as a non-critical event from the platooning system's perspective.
- Platooning would sometimes cut-out during routine operations. Several reasons could normally be identified, but some could have been avoided with longer development time.
- Platooning will continue even if the GPS is no longer able to be communicated. There is redundancy in the radar, which should mitigate problems in platooning. This was reported and a part of the system design. However, there is chance for compounded problems, for example a cut-in during GPS dropout, which was not tested.
- Platoon system will still fail to function and disable CMBS/ACC if the vehicle is not started according to the operating guidelines (i.e. turn key to accessory, before turning on the engine).

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Appendix A – Testing Equipment and Facility

A.1 Testing Equipment

OXTS RT3000 V2 and V3:

- IMU and GPS unit
- Measures position, orientation and dynamics of a vehicle in real-time
- Position accuracy: 2 cm
- Slip angle accuracy: 0.15°
- 100 Hz data output rate

OXTS RT-Range:

- V2V, V2X and Vehicle-to-lane measurements in real-time
- Up to 1km range between hunter and targets
- Can measure up to 4 moving targets simultaneously

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Freewave Differential Correction:

- Use local base station's signal to improve GPS' accuracy

ABD Guided Soft Target (GST):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 100 km/h (27.8 m/s)
- Forward acceleration up to 0.2g and deceleration up to 0.8g
- Synchronization with the test vehicle with path following ability
- Has heavy duty ramps for Semi testing

DSD Ultraflat Overrulable Robot (UFO):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 65 mph (29.1 m/s)
- Forward acceleration up to 0.3g and deceleration up to 0.6g
- Synchronization with the test vehicle with path following ability
- Removable side ramps and batteries

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A.2 Testing Targets

EuroNCAP Soft Car 360:

- Representative of a small hatchback from all angles
- Can take impacts and be reassembled in 10-15 minutes

Pedestrians: Static Adult and Static Child

- 4activeSystmes static dummies that replicate properties of stationary pedestrians in size, shape and radar cross section
- Can take impacts up to 60 km/h (16.7 m/s)

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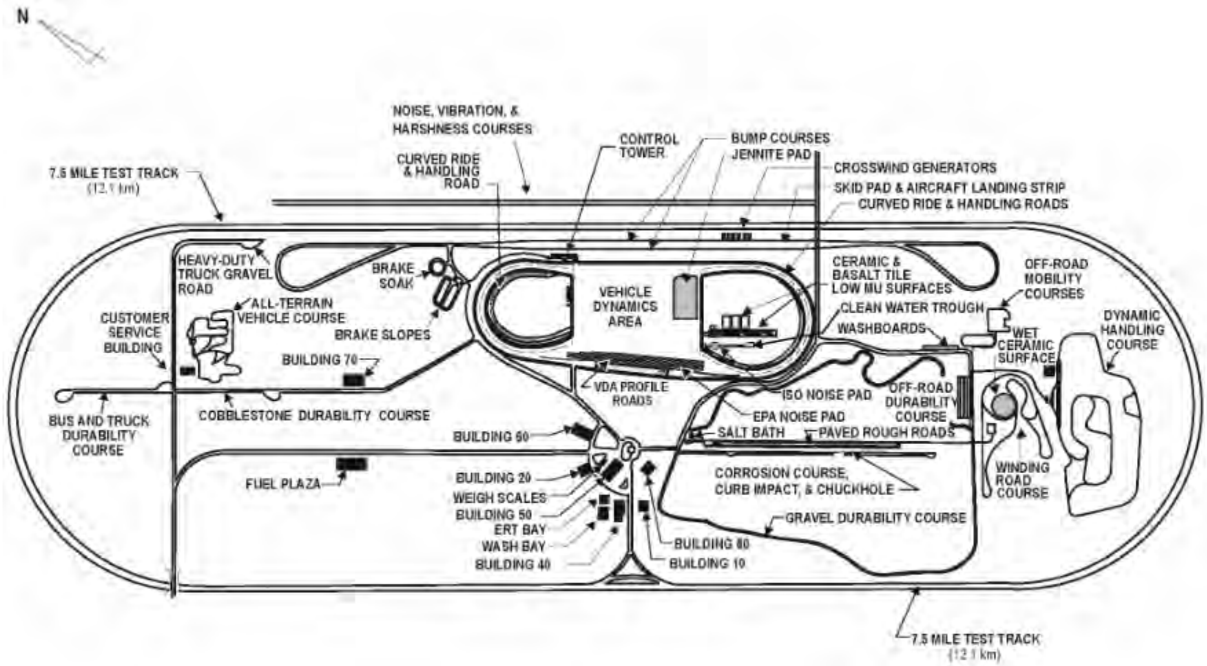
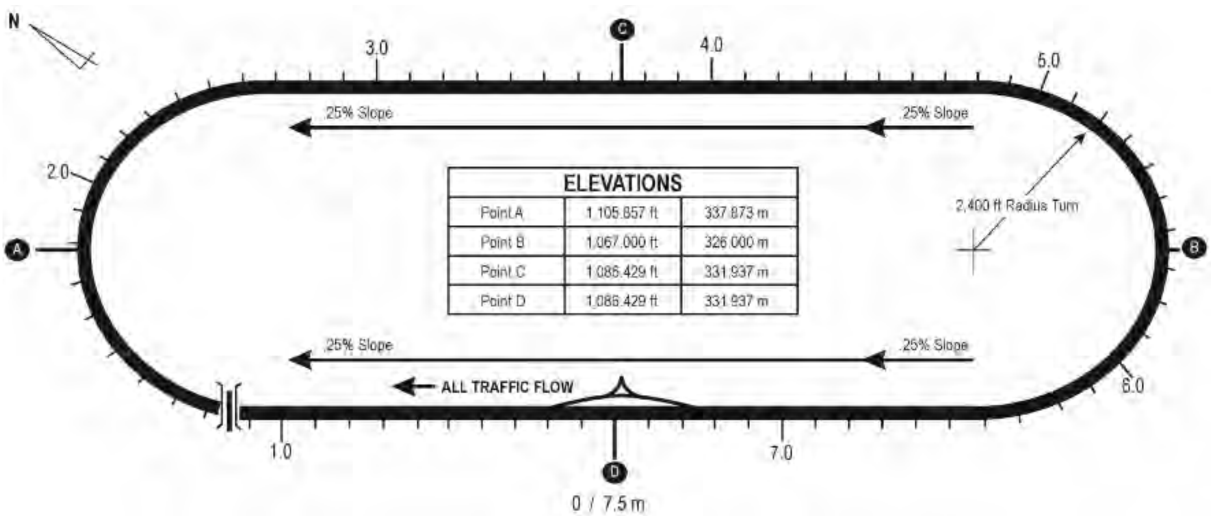
A.3 Testing Facilities



TRC Overall facility



7.5 miles High-speed Test Track

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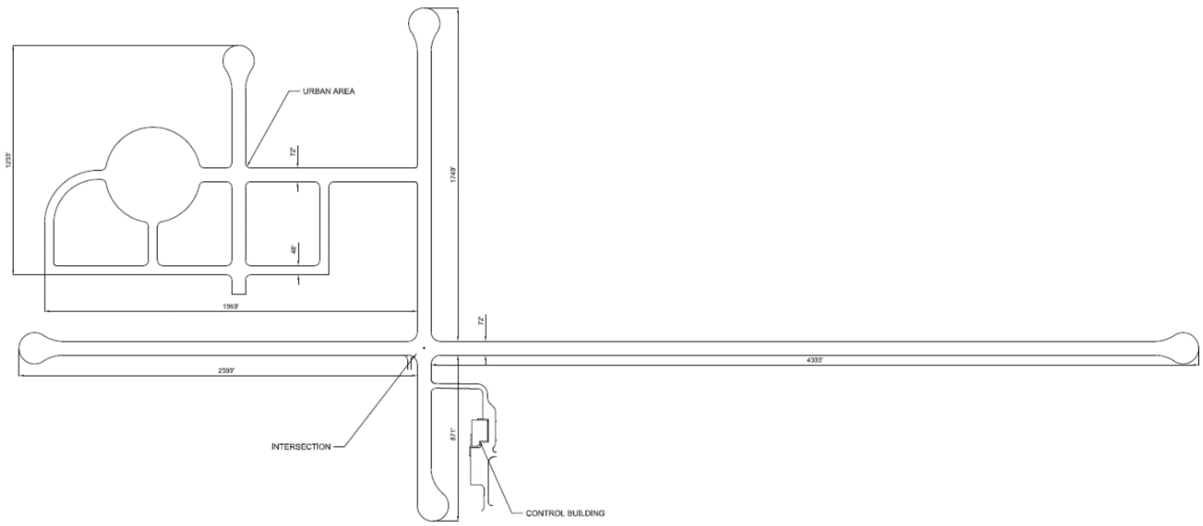
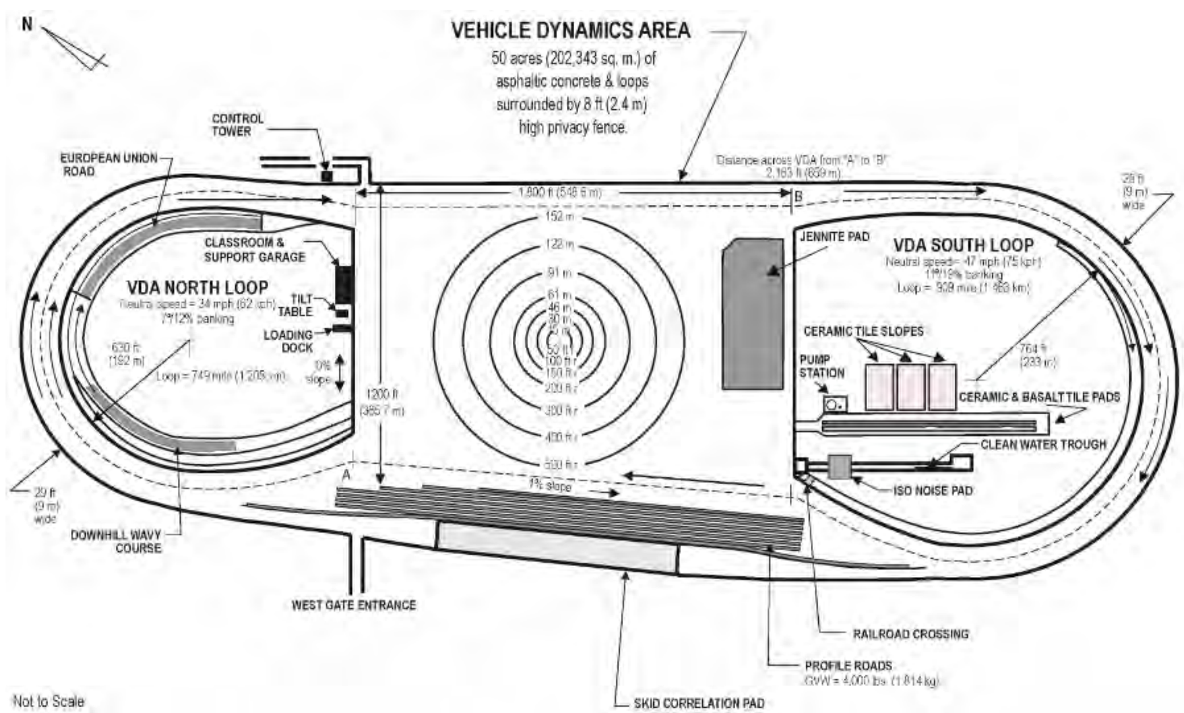


SMARTCenter

6-lane high-speed intersection with larger leg of 1.2 miles for heavy duty vehicles to reach up to 65 mph (29.1 m/s) at the intersection. Urban network with city blocks and 152 m (500 ft) radius roundabout.



Vehicle Dynamics Area

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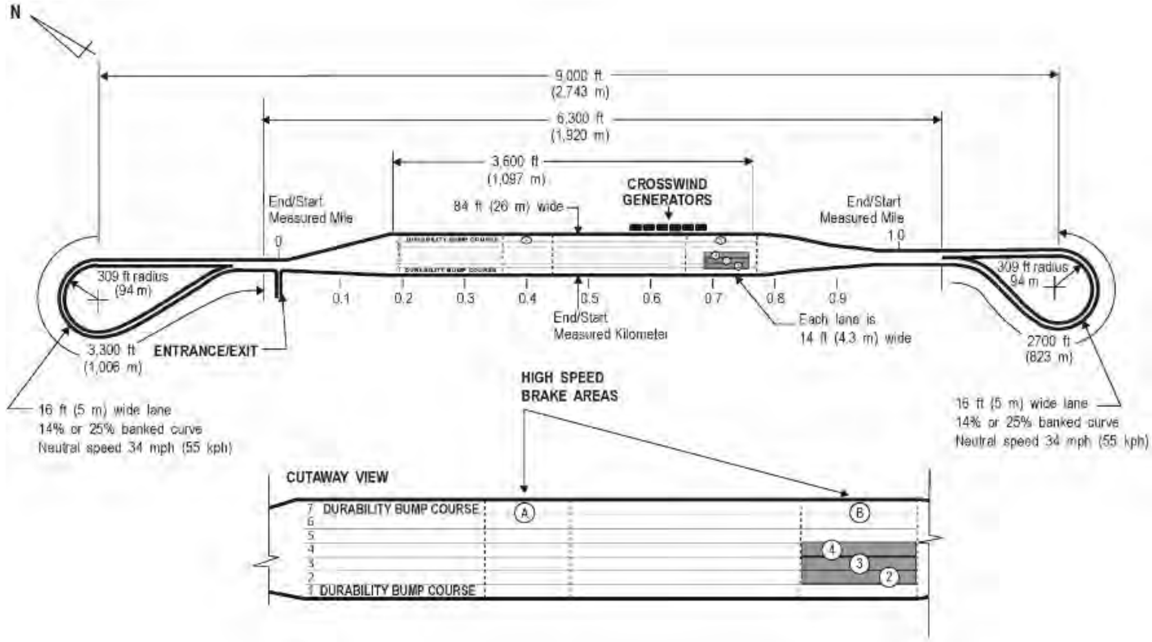

Skid Pad

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Appendix A4
Truck Safety Management Plan

SAFETY MANAGEMENT PLAN VERSION 3 (TRACTOR DEPLOYMENT)

Ohio Rural Automated Driving Systems (ADS) Project

Prepared for: DriveOhio

Prepared by: CDM Smith with TRC and Bosch

May 19, 2023

CDM Smith

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Acronyms and Abbreviations

ACC	adaptive cruise control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
ADS Project	Ohio Rural Automated Driving Systems Project
AEB	automatic emergency braking
AEBS	automatic emergency braking system
ASIL	Automotive Safety Integrity Level
CAM	corrective action management
CASC	TRC Corporate Administrative Safety Committee
CE	controlled environment
ConOps	Concept of Operations
DMP	Data Management Plan
DPP	Data Privacy Plan
EMS	Emergency Medical Services
FMCSA	Federal Motor Carrier Safety Administration
FOG	Facility Operating Guidelines
GIS	geographic information system
HARA	Hazard Analysis and Risk Assessment
HMI	human machine interface
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transportation System
LKAS	lane keeping assistant system
NHTSA	National Highway Traffic Safety Administration
ODD	operational design domain
ODOT	Ohio Department of Transportation
PII	personally identifiable information
PUC	Public Utilities Commission
QG	quality gate
SAE	SAE International, formerly Society of Automotive Engineers
SGO	Standing General Order
SMP	Safety Management Plan

SOP	Safety Operational Plan
SOTIF	safety of the intended functionality
TRC	Transportation Research Center
UC	University of Cincinnati
USDOT	United States Department of Transportation
V2V	vehicle to vehicle
VRU	vulnerable road user

Section 1

Introduction

1.1 Project Overview

The U.S. Department of Transportation (USDOT) awarded an Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of the Ohio Department of Transportation (ODOT), JobsOhio, Transportation Research Center (TRC), Bosch, Ohio University (OU), University of Cincinnati (UC), and Southeast Ohio community partners. The Ohio Rural Automated Driving Systems Project (ADS Project) will pilot how automated vehicles could improve safety for drivers, passengers, and other travelers in rural settings.

The intent of the project is to test two automated tractors with semi-trailers, in Ohio, capable of Level 1+ automation per the SAE International levels of automation. Level 1+ automation includes driver support features such as adaptive cruise control and other related technologies to support truck platooning operations. The two Advanced Driver Assistance System (ADAS) tractors require that the driver is always engaged with the driving task. The scope of the project is to demonstrate ADAS tractor automation technologies with a host fleet partner. The full description of the ADAS tractor technologies is captured in the ODOT Invitation to Bid (Reference No. 554-23, Ohio Rural Automated Driving System Project). The host fleet will be operating the ADAS tractors in-revenue service on public roads in both single mode and truck platooning mode. Truck platooning involves two tractors, with semi-trailers, traveling closely together in a cooperative manner, which can improve safety and fuel efficiency. System validation tests will occur on a closed test course prior to deployment on public roads. The truck platooning system will rely on radar and cameras to enable lane centering and platooning functionality. The host fleet deployment will gather data in both single-truck mode, as well as truck platooning mode. The data gathered will support analysis of potential safety and efficiency benefits of the technology.

Since the goal of the project is to collect vehicle operating data during in-revenue service by a host fleet carrying real freight on public roads in Ohio, the two ADAS-equipped tractors will undergo a set of controlled environment (CE) tests at the TRC Test Facility per a CE Test Plan developed by the project team, as well as a risk assessment conducted by Bosch per its normal new product delivery and release processes. Additionally, the two ADAS-equipped tractors will be driven by TRC professional drivers over two specific routes to further test the truck platooning technology on public roads before delivery of the tractors to the host fleet. Following the completion of testing, the host fleet will operate the ADAS-equipped tractors in-revenue service for about 12 months and collect vehicle operating data. The data collected will be critical to project goals, assisting researchers involved in vehicle automation well into the future and allowing the project team to measure project performance.

1.2 Safety Management Plan

The Safety Management Plan (SMP) is a companion document to the systems engineering documentation, including the Concept of Operations (ConOps), System Requirements, Interface Control Document (ICD), Data Management Plan (DMP), Data Privacy Plan (DPP), Human Use

Approval Summary, Project Evaluation and Performance Measurement Plans, and the Safety Operational Plans (SOP) for each partner operating the tractors on public roads. The purpose of the SMP is to identify the safety risks associated with the project's tractor deployment and describe the process and related documentation used by the project team before releasing the two ADAS tractors to the host fleet. The SMP describes the potential safety risk scenarios related to the deployment, assesses the level of risk for each safety scenario using a Risk Assessment Matrix that is loosely based on the Automotive Safety Integrity Level (ASIL) process defined by the International Organization for Standardization (ISO) 26262, provides mitigation strategies, and puts forth SOPs from TRC and the host fleet for deployment on public roads.

The SOP is developed in coordination with the proposed operational practices described in these conceptual documents for each deployment partner (TRC and the host fleet). The SOP provides and documents the guidance on designing a safety-critical system that can eliminate hazards from the design, reducing risks by modifying the design to lower the probability of the occurrence of the hazard, or at minimum, mitigating the impact of the hazard if it does occur, and any limitations on the use of the truck platooning technologies on the ADAS tractors and operations by the partner drivers. The System Requirements include functional requirements, interface requirements, data requirements, performance requirements, security requirements, etc., for all systems that will be deployed as part of the ADS Project. The SMP lists all requirements and the safety risks associated with those requirements. The Interface Control and System Requirements documents should refer to the SMP to make sure all safety risks listed in this plan are addressed while designing and testing the system.

The SMP will use references to project partner documents (i.e., SOP) and at a high level describe the underlying needs of the public road deployments to validate the overall safety and understand the impacts of various scenarios. The approach to developing the risks was to collaboratively identify and document them with the project team but with each project partner having specific roles.

1.3 Operating Scenarios

This SMP highlights the risks and identifies mitigations based on an automation scenario. There is the possibility that some tests and data collection runs are completed without the autonomy stack engaged in the vehicle operation. The scenarios are defined by the project team with inputs from a variety of sources and are captured in the CE Test Plan. The CE Test Plan is prepared by TRC with direct input from Bosch. The CE Test Plan will be a project deliverable and available with other project reports.

1.4 Project Vehicles

The ADS Project has two class 8 tractors which have been retrofitted with ADAS technologies to permit truck platooning operations. The project tractors are:

- 2018 Navistar Class 8: VIN number 3HSDZTZR9JN324882
- 2021 Navistar Class 8: VIN number 3HSDZTZR4MN334627

1.5 Document Overview

This document includes the following chapters, which detail the project's tractor safety-critical system that is designed to address operational risks for deployment. The SMP will make references to other project deliverables, project partner SOPs, and will reference as such.

- Section 1 – Introduction describes the project overview to the SMP.
- Section 2 – Safety Risk Process and Approach describes the overall safety risk process and approach to safety risk management.
- Section 3 – Safety Analysis and Risk Assessment Plan identifies the safety risks and provides an analysis and assessment of the safety scenarios identified within the tractor deployment.
- Section 4 – Safety Operational Plan describes the safety operational concept including functional requirements, and system-wide fail-safe mode.
- Section 5 – Coordination with Other Tasks describes how this SMP coordinates with related project deliverables.
- Section 6 – Summary/Conclusions summarizes this document's conclusions.

Section 2

Safety Risk Process and Approach

This section describes the safety risk approach for the project's tractor deployment and the procedures that the project team will use to manage risks.

The safety assessment and requirements process that Bosch follows is an interpretation of the process outlined in the ISO26262:2018 standard. This process has been designed to provide a set of requirements and measures to ensure that the system is safe to drive under the boundary conditions determined by the project. Due to the nature of this project, the final safety will be heavily dependent on the usage of trained drivers and constrained operating conditions (limitations of the use of the technology and other operating limitations captured in the Operational Design Domain [ODD]) that would not be possible with a system or component release for use by the general public.

The SMP will reference project partner documents but provides a high-level view of the safety risks, performing a Hazard Analysis and Risk Assessment (HARA), developing mitigation measures, and creating a safety operational concept plan based on the identified safety requirements (Fail-Safe System Mode, Quality Training, etc.). The SMP must be approved by ODOT's DriveOhio before the project tractors can be operated on public roads. Figure 2-1 provides a workflow of the process used by the project team that results in the Bosch Release Note that permits the delivery and use of the two ADAS tractors to the host fleet. The SMP process starts with the ConOps and the use cases that were developed. These feed the Safety Evaluation. The tractors undergo test track testing (at TRC) of specific technology features which leads to a CE Test Plan and CE testing at the test track. The CE testing is summarized in a report which is input to the deployment plan for public roads. The ADS Project has three public road deployments (two using TRC drivers and the third by host fleet drivers). Before the ADAS tractors are operated on public roads for the first and second deployments, the TRC drivers are trained using the inputs from the CE test results, as well as the Safety Evaluation from Bosch. The Safety Evaluation helps inform the Driver Training Plan, as well as the SOP so that those responsible for the operation of the vehicles know the associated vehicle capabilities and serves as the basis for the Mitigation Measures that result from the Safety Evaluation's risk assessment. The project team will both have checks in place to assure that the mitigations are implemented to reduce risk and are documented in the project partners SOPs. The public road deployments consist of two deployment routes in central Ohio and southern Ohio and the tractors are driven by TRC trained drivers. These deployments may add more information in a TRC Suggested Platooning Conditions document about the ADAS-equipped tractor technologies for inclusion in the SMP. Once the two TRC deployments are completed, the host fleet drivers will be trained at TRC. This training is mandatory before the two ADAS tractors can be delivered to the host fleet. Also, the host fleet drivers will join the TRC drivers for ride-alongs during select portions of the deployments. The SMP is a living document and will be updated as needed but the ODD needs to be finalize before the delivery of the two ADAS tractors to the host fleet. The SMP and its referenced partner documents are inputs to the host fleet SOP. The host fleet SOP must address the technology limitations (stated in Section 4.5.2) and other related limits of use of the truck platooning technology in this SMP. This requirement was stated in the ODOT Invitation to Bid (Reference No. 55423).

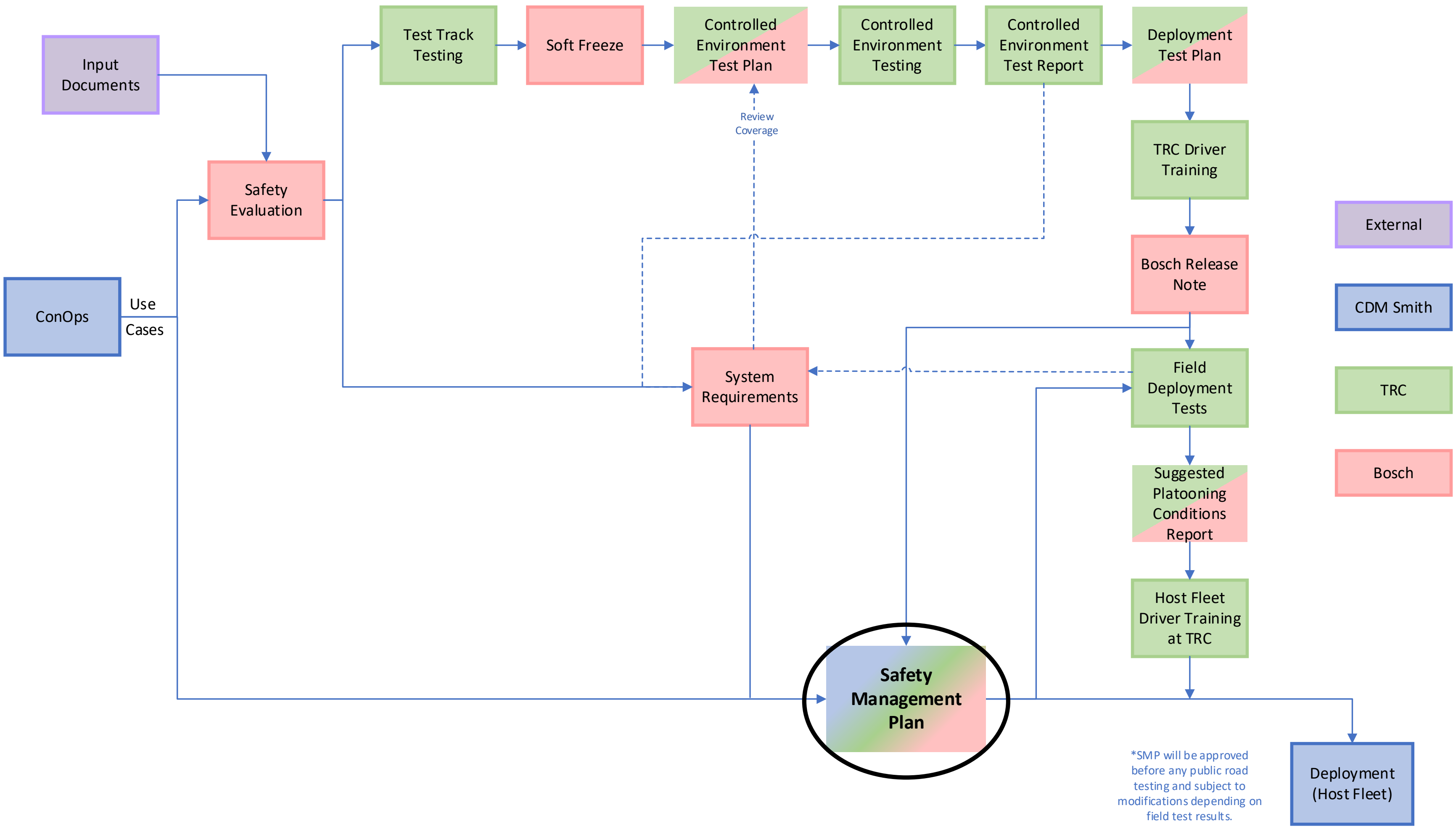


Figure 2-1. Safety Management Plan Process Flowchart

2.1 Input Documents

The basic project concept, use cases, and boundary conditions are provided by the ConOps document. This document provides the context for the safety analysis. There are several predecessor projects that have informed the ADS Project. These projects have provided a wealth of safety related analyses to use as source documentation. The ENSEMBLE (publicly funded in the European Union) has defined a full high-level system design for truck platooning including use cases, system requirements, protocol and test definitions, and safety documentation. These documents are augmented by analyses from USDOT regarding heavy truck platooning and braking systems. Finally, Bosch has several internal development projects that have conducted system and safety requirement analyses. These internal documents will be cross-referenced for relevant hazard information to ensure a full picture.

Project Input Documents

- Concept of Operations (ConOps)

Public Input Documents

- National Highway Traffic Safety Administration (NHTSA) Hazard Analysis of Concept Heavy-Truck Platooning Systems (DOT HS 813 065)
- Federal Motor Carrier Safety Administration (FMCSA) Analysis of Variability in Heavy Truck Braking Systems (FMCSA-RRT-19-005)
- ENSEMBLE Item Definition (ENSEMBLE D2.10)
- ENSEMBLE Hazard and Risk Assessment (ENSEMBLE D2.11)
- ENSEMBLE Safety Case (ENSEMBLE D2.12)
- ENSEMBLE Safety of the Intended Function (ENSEMBLE D2.13)

Bosch Internal Input Documents

- Bosch Platform Platooning Hazard Analysis and Risk Assessment
- CONCORDA Platooning Safety Concept and Road Release
- Lane Centering System – Safety Case

Safety Artifacts

- Item Definition
- Hazard Analysis and Risk Assessment
- Safety Measures
- Assumptions for the platooning system

The Item Definition determines the system under analysis from a safety perspective. It is not a requirement document, rather a set of assumptions and a description that provide a basic common understanding of the system for further safety analysis.

This definition in turn allows determination of the relevance of any use cases and identified hazards from the input documents. As the item definition includes constraints that are far narrower than any of the three source analyses (USDOT, ENSEMBLE, and Bosch platform), the project team will use the existing safety of the intended functionality (SOTIF), and HARA documents as a superset of the relevant hazards for the current project and are summarized in the Safety Evaluation Report.

The output of the HARA is a set of safety measures and assumptions. The safety measures will include items that will lead directly to system and software requirements, operational boundary conditions, and test requirements. A summary of the HARA, as well as a full list of safety measures, is included in Section 3 of this document.

2.2 System Requirements

The System Requirements document is the link between the safety measures and the system running in the vehicle. Full coverage of the safety measures shall be documented in the system requirements table to ensure that they are implemented in the software. The requirements of the system will also inform the CE and Deployment Test Plans, so that the project team has confidence that all implemented requirements have documented test cases before the release of the vehicle for use on public roads.

2.3 Risk Process and Approach

To protect the safety of operators, pedestrians, bicyclists, and other motorists, a process inspired by the ISO 26262 is used for testing, deployment, and closeout stages. Figure 2-2 illustrates the development of the SMP, which follows the process defined in the USDOT guidelines.

1. Identify safety scenarios at system level as defined in the ConOps.
2. Assess the level of risk for each safety scenario.
3. Develop a safety operational concept for each scenario if it is identified as high/medium risk.

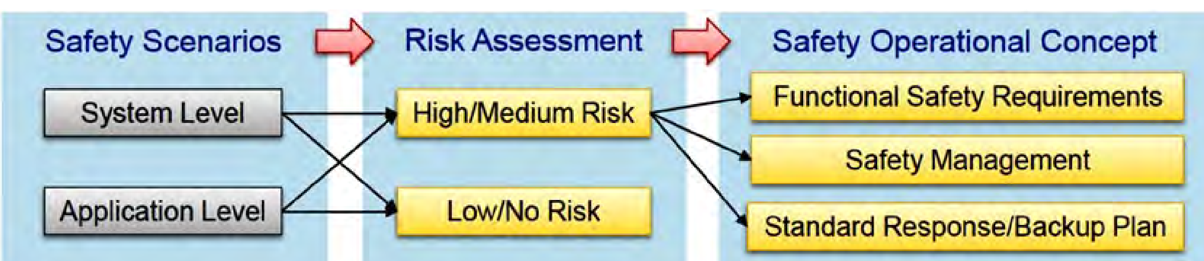


Figure 2-2. Safety Management Plan Development Process
(Source: USDOT Guidance Summary on Safety Management Plan)

It is anticipated that through each phase of the project, there is potential for additional risks to be identified. When that is the case, the project team will identify the risk and determine what, if any, mitigations are required to continue to assure the safety of the surrounding individuals. These risks and limitations of use will be documented in the SMP, and its reference partner documents.

2.4 Safety Stakeholders

There are many stakeholders that are responsible for the development, testing, and deployment of the project, as well as stakeholders that are responsible for maintaining and operating the roadway network. It is the project team's responsibility to assess the potential hazards and mitigation strategies with stakeholders once complete, so they are aware of the potential risks and the mitigations put into place.

The following are safety response stakeholders, for the tractor deployment.

- USDOT (including FMCSA)
- ODOT – Traffic Safety, Construction, Maintenance, Geographic Information System (GIS)/Intelligent Transportation System (ITS), Information Technology (IT), Telecom Programs (including equipped snowplows), DriveOhio
- Ohio State Highway Patrol/Public Utilities Commission (PUC)
- Local Police, Fire, and Emergency Medical Services (EMS)
- Transportation Research Center, Inc.
- Bosch

2.5 Law Enforcement and Emergency Responder Coordination

State and local agencies have their own emergency response plans and law enforcement for various events, such as severe incidents, natural disasters, or planned events. The project team will coordinate with the Ohio State Highway Patrol regarding the use of the two ADAS-equipped tractors on public roads. Also, the Highway Patrol prepared a truck platooning white paper which permits TRC and the host fleet to operate the two ADAS-equipped tractors in truck platooning mode (per the SMP limitations of use in Section 4.5.2) on Ohio public roads. This white paper will be placed on the two ADAS-equipped tractors for access by the trained drivers to show any law enforcement agent.

The project team will work with the Highway Patrol for all public deployment routes in Ohio and conduct Law Enforcement Stakeholder meetings. The purpose of these meetings is to educate law enforcement about the technology and use of the technology along specific routes. Also, ODOT's DriveOhio will work with the Highway Patrol, the host fleet, and any adjacent state DOTs if the host fleet in-revenue routes go beyond Ohio for truck platooning operations. The Highway Patrol's truck platooning white paper only covers Ohio roads. This document can be found in Appendix A.

2.6 Safety Risk Monitoring

The project team will ensure safety risk controls are effective and new safety risks are identified by considering the following items during a scheduled safety review:

- Verifying that periodic checks on the equipment, software, interfaces, and processes are being conducted.
- Reviewing feedback and information received from the operators.

- Reviewing any incident reports.
- Keeping up to date with best practices and lessons learned from similar deployments.
- Coordinating with law enforcement, as necessary.
- Conducting internal reviews of project documentation.

TRC/Bosch will be monitoring the safety risks and track them throughout the deployment duration via the safety review process. Details on TRC's SOP are summarized in Section 4.

2.7 National Highway Traffic Safety Administration Automation Incident Reporting

The NHSTA has crash reporting requirements for Level 2 ADAS-equipped vehicles. This requirement is based on the Standing General Order (SGO) reporting obligations for ADAS-equipped vehicles and equipment manufacturers served with SGO. The entities named in the SGO must report a crash if Level 2 ADAS-equipped vehicle was in use at any time within 30 seconds of the crash and the crash involved a vulnerable road user or resulted in a fatality, a vehicle tow-away, an air bag deployment, or any individual being transported to a hospital for medical treatment or vulnerable road users (VRU) and this needs to be reported within 1 to 10 days depending upon the crash severity type.

2.8 State of Ohio Incident Reporting

The State of Ohio Highway Patrol is requesting that all incidents involving law enforcement, regardless of the nature of the law enforcement incident, be reported by TRC and host fleet (for their respective vehicles) using the website below during the duration of the deployment on the public road routes in the Athens area. Appendix B provides a copy of the Incident Report form.
https://ODOT.formstack.com/forms/driveohio_av_reporting

Section 3

Safety Analysis and Risk Assessment Plan

3.1 General Information

The primary goal of this section is to describe the feature level item, collecting all relevant information. This shall be used to perform a HARA and later to derive a Functional and Technical Safety Concept for the feature level item in the series phase. The section shall be finished prior to the series release of the feature level item. Note: The assumed preconditions within this document may be replaced or complemented by other documents in the future (e.g., by Functional Safety Concept) during further project phases.

The Feature Level Item shall be described in a functional way. If a technical solution is known and shall be used, this shall be highlighted in this document. Material in this section provides requirements for operating the tractors in truck platooning mode, which need to be inserted into partners' SOPs.

3.1.1 Definitions, Acronyms, Abbreviations, References

Definitions

- Leading Tractor: Navistar International LT625 Class 8 Truck MY2018 with Bendix Wingman Advanced (= Radar)
- Following/Trailing Tractor: Navistar International LT625 Class 8 Truck MY2021 with Bendix Wingman Fusion 2.10 (= Camera + Radar)

Intended Use/Purpose of the Feature Level Item

The considered Feature Level Item describes the function "Platooning" for the use in defined U.S. tractors on selected highways and freeways per the ODD (Section 4.5.2).

Communication and Functionality

A vehicle-to-vehicle communication channel is used to provide position, acceleration, and brake information for the following truck. The following truck is equipped with radar and can measure the distance, speed, and acceleration/deceleration. Thereby, the following truck can perform control interventions with very low latency based on operations in the leading truck. Both tractors are equipped with market approved automatic emergency braking system (AEBS) functions which ensure that in case of a failure of the platooning function, a crash is avoided.

Driver

Drivers shall only use the platooning feature if they have had specific training in its use and have documented project approval.

Item

The Item is limited to the radar sensor and controller implemented in the following truck, the interface to the driver, the interface to the vehicle, and the communication to the front truck. The 2021 Navistar Class 8 tractor (VIN 3HSDZTZR4MN334627) is the follow tractor while in truck platooning mode.

List of Feature Functions

- Communication between trucks
- Acceleration
- Deceleration
- Driver Information

3.1.2 Operating Modes, States, Scenarios, and Environment

This section defines operating modes and states, operating scenarios, and the operating environment if relevant for the Feature Level Item.

States

- Passive
- Engaged
- Disengaged
- Failure

Operating Environment

Road Types	The function is allowed on select roadways only. Each route that the platooning function will be used on must have documented approval from the project team. Per this SMP (Section 4.5.2), the function is allowed on the following road types: Divided highway, undivided highway, principal arterial, and major collectors.
Weather Conditions	The drivers need to decide if the weather conditions are okay for testing the function. The drivers will be briefed that they can consider all relevant weather conditions.
Market Regions	USA

Design Constraints

- Stop and Go is not part of the platooning function; the vehicle system must be re-engaged after stand-still.
- The minimum distance between both trucks is defined as 1.4s. CE Test Report will confirm the distance. (see HARA assumptions)

Vehicle Speed	Minimum Setting (1.4 s)	Maximum Setting (3.0 s)
30 mph	62 ft	132 ft
45 mph	93 ft	198 ft

60 mph	124 ft	264 ft

Communication System

The following communication systems are used:

- Communication to the brake system
- Communication to the engine controller
- Communication with the other vehicle
- Communication to the driver

The following information is available:

- Position of the leading vehicle
- Distance between the vehicles (radar calculated and validated by GPS)
- Target acceleration/deceleration of the leading vehicle
- Actual acceleration/deceleration of the leading vehicle

The communication system shall have the necessary capabilities to ensure the required:

- Latency
- Reliability
- Availability
- Integrity

Actuators

The trucks are equipped with publicly released actuators. The existing safety concept of all actuators is unchanged and still valid. This means that all required safety measures and limitations are implemented and approved for all actuators.

The platooning function will use the existing interface of the adaptive cruise control (ACC) function to the engine and brake control with existing controllable limitations.

The platooning function will request acceleration and deceleration torques to maintain the chosen distance of the following truck. All interventions of the platooning function will also be controllable since only the ACC interface is used. Brake interventions of the platooning function will be indicated by the brake lights since the interface of the ACC function is used.

The platooning function will not request steering intervention; there is no interface between the platooning function and the steering system or steering components.

Drivers

- In every truck there is one trained driver present, who is monitoring the vehicle operation.

- Every driver is trained for using the platooning function.
- TRC defined the training plan for drivers.
- The drivers can communicate with each other via radio.
- The driver of the following truck needs to engage the platooning mode when both drivers agree it is safe to do so.
-
- The driver is free to activate ACC or the platooning function. Both functions active at the same time in the following truck is not allowed.
- The drivers need to be informed about legal regulations and allowed exceptions.

Information for the Drivers and Surrounding Traffic

- The driver is informed of whether the platoon is active or not.
- The surrounding traffic has information that the trucks are in platoon mode. This will be done with the “chicken lights” with a purple-like color located on the side of each tractor under the sleep area and activated when the truck platooning technology is engaged.

3.2 Bosch Platooning Function HARA

3.2.1 Assumptions and Boundary Conditions

Functions Setup

Bosch Engineering has performed a HARA as a systematic approach to analyze major risks and to define adequate measures for the ADS Project platooning function which will be used in defined U.S. trucks on selected highways and freeways. In the following section, the considered boundary conditions and the resulting requirements will be described.

Communication and Functionality

A vehicle to vehicle (V2V) communication is used to provide position, acceleration, and brake information for the following truck. The following truck is equipped with radar and camera and can measure the distance, speed, and acceleration/deceleration. Thereby, the following truck can perform those interventions with very low latency from operations in the leading truck. Both trucks are equipped with market approved AEBS functions (in the following AEB function) which ensures that in case of a failure of the platooning function, a crash is avoided. The AEB in the front vehicle can be disabled to reduce the risk of unintended interventions. The timeslot between the platooning vehicles shall not decrease below 1.4 seconds.

Driver

- In every truck, there is at least one trained driver present who is monitoring the vehicle operation.
- Every driver must be trained for the platooning function.

- The drivers shall only use the platooning feature if they have had specific training in its use and have documented project approval.
- TRC is defining the training plan for the drivers.
- The drivers can communicate with each other via radio.
- The driver of the following truck needs to engage the platooning mode when both drivers agree that it is safe to do so.
- The driver of the following truck is free to either activate ACC or the platooning function. Both functions active at the same time is not allowed. The drivers must be trained.
- The drivers must be informed about legislative regulations and allowed exceptions.
- Drivers will be trained professionals with lower reaction times than average drivers.
- Falling asleep is considered an abuse and not considered in evaluations.
- Distracted driver refers to a temporary and short duration loss of focus (<1s reaction time).
- Cut ins from external vehicles are evaluated but it is assumed that platooning will be disengaged by driver in this operating situation.

Weather Conditions

The drivers must decide if the weather conditions are okay for testing the function. The drivers will be briefed that they can consider all relevant weather conditions. The platoon system should only be used when it safe to do so. Conditions where the platoon system should not be used include, but are not limited to snow, ice, heavy rain or fog, very heavy wind, or other conditions which limit driver visibility or vehicle control. The deployment partners (TRC and host fleet) will further define truck platooning operations based on the SMP and its referenced documents in their SOPs.

Requirements to the Trucks

The tractors are equipped with publicly road released sensors and actuators. The existing safety concept of all actuators is unchanged and still valid. This means that all required safety measures and limitations are implemented and approved in all actuators.

Interfaces of the Platooning Function

- The platooning function will use the existing interface of the ACC function to the engine and brake control with the existing and controllable limitations.
- The platooning function will request acceleration and deceleration torques to maintain the chosen distance of both trucks. All interventions of the platooning function will also be controllable since only the ACC interface is used.
- Brake interventions of the platooning function will be indicated by the standard brake lights since the interface of the ACC function is made through the existing braking and propulsion system.

- The platooning function will not request steering interventions. There is no interface between the platooning function and the steering system or steering component.

Information for the Drivers and Surrounding Traffic

- The drivers must be informed if the platoon has been connected successfully. This information will be displayed on the human machine interface (HMI).
- The platooning vehicles must provide warning to the surrounding traffic to keep sufficient distance from platoon vehicles.
- Traffic warning system will be implemented via the chicken lights as agreed on with Ohio State Highway Patrol.

3.3 Hazard Analysis and Risk Assessment Preparation

3.3.1 Considered Situations

The following situations have been evaluated in the HARA:

- Highway traffic behind, forward motion, platoon engaged
- Highway traffic behind, forward motion, platoon disengaged
- Highway traffic behind, forward motion, platoon engaged, high lead vehicle deceleration
- Highway forward motion, platoon engaged, distracted drowsy unfocused driver
- Highway traffic beside, forward motion, platoon engaged
- Highway traffic beside, forward motion, platoon disengaged
- Highway traffic beside, forward motion, platoon engaged cut-in

3.3.2 Considered Malfunctions

The following malfunctions have been considered:

- Missing acceleration
- Unintended acceleration
- Too much acceleration
- Not enough acceleration
- Missing deceleration
- Unintended deceleration
- Too much deceleration
- Not enough deceleration
- Too high distance
- Too low distance
- No status of platooning

- Unintended platooning indication on
- Unintended platooning indication off
- Missing platoon activation
- Unintended platoon activation
- Missing platoon deactivation
- Unintended platoon deactivation

Table 3-1. Safety Evaluation

Operational Situation	Description of Failure Effect on vehicle level	Effect of malfunctioning behavior / harm (potential consequences of hazardous event)	Exposure	Severity	Controllability	Exposure Justification	Severity Justification	Controllability Justification	ASIL
Highway, traffic behind Forward motion platoon engaged	unintended acceleration	potential crash due to reduced stopping distance	E4	-	C0	Driving on highway VDA 702_2015 FO010	C0, so no S needs to be defined	C0 - Generally controllable. Driver has sufficient time to abort the function (button, brake pedal) and take over vehicle control. Acceleration is limited by ACC to controllable levels.	n/a
Highway, traffic behind Forward motion platoon engaged	unintended deceleration	unable to maintain platooning due to exceeding nominal platooning distance. A drowsy driver may begin to drift, unaware platoon has been disengaged. Possible crash with external vehicle(s).	E4	-	C0	Driving on highway VDA 702_2015 FO010	C0, so no S needs to be defined	C0 - generally controllable. Vehicle decelerates slowly and following vehicles can control situation by breaking/overtaking. Deceleration is limited to controllable levels by ACC.	n/a
Highway, traffic behind Forward motion platoon engaged High lead vehicle deceleration	unintended acceleration	potential crash due to reduced stopping distance	E1	S2	C2	Driving on highway Driving with deceleration over ~ 6 m/s^2 VDA 702_2015 FB140	S2: Front/rear collision with 20 < delta v < 40 km/h	C2 - Normally controllable. The driver must recognize and actively needs to brake or steer to avoid danger.	QM

Operational Situation	Description of Failure Effect on vehicle level	Effect of malfunctioning behavior / harm (potential consequences of hazardous event)	Exposure	Severity	Controllability	Exposure Justification	Severity Justification	Controllability Justification	ASIL
Highway, traffic behind Forward motion platoon engaged High lead vehicle deceleration	missing deceleration	potential crash due to reduced stopping distance	E1	S2	C2	Driving on highway Driving with deceleration over ~ 6 m/s^2 VDA 702_2015 FB140	S2: Front/rear collision with 20 < delta v < 40 km/h	C2 - Normally controllable. The driver must recognize and actively needs to brake or steer to avoid danger.	QM
Highway, forward motion platoon engaged Distracted drowsy unfocused driver	unintended acceleration	trained driver reaction time is increased while presented with possible crash conditions due to reduced stopping distance	E2	S2	C1	Driving on highway VDA 702_2015 FO010 (E4) Reduction for distraction E2	S2: Front/rear collision with 20 < delta v < 40 km/h	C1 - simply controllable. The driver must recognize the trajectory is incorrect and actively needs to brake or steer to avoid danger.	QM

3.3.3 Hazard Analysis and Risk Assessment Results and Derived Measures

The previously mentioned situations and malfunctions have been combined to achieve a matrix. For every entry in the matrix, the controllability and severity has been derived considering ISO 26262:2018 and the before mentioned assumptions. It has been considered that the AEB function will support the driver of the following truck if the distance between both ADAS-equipped tractors decreases. Thereby, a collision of both trucks is avoided. This led to the requirement that the platooning function shall only be used when the AEB function of the following truck is available. A distracted driver results in a reduced reaction time of the driver; therefore, measures must be defined to reduce the risk of distracted drivers. Possible measures include:

- Drivers always have hands on the steering wheel
- Maintain radio communications between vehicles
- Reconfirmation of platoon operation every 20 minutes
- Trained driver pre-trip checklist completed prior to each drive
- Chicken lights are working and active when platooning

Section 4

Safety Operational Plan

The project deployment partners (TRC and host fleet) have SOPs to guide the appropriate use of the tractors, outlining when the ADAS software can be enabled, how to operate it appropriately when it is engaged, and other operational guidance. System safety is always the highest priority when the vehicle is in use. This requires an in-depth knowledge of the full system through scenario-based closed-course testing and having trained drivers. These SOPs will be updated with the information in this SMP and its reference documents for public road deployments. Also, TRC's SOP has application for its test track operations.

The system under test is a prototype research platform and the goal of this project is to collect and provide in-revenue service vehicle operating data. The approach to achieve safety is to put sufficient safety measures around the operation of the vehicle by having an appropriate understanding of the system's limitations and have the expectation that the driver is fully in control and responsible for the vehicle's actions. In addition, having the capability to instantaneously take manual control of the tractor by the driver is required for this approach to be valid. The following paragraphs define TRC's SOP approach to establishing a plan for determining appropriate safety measures.

Testing will take place in two environments over the course of this program. Controlled Environment Prove-out will be conducted under closed course conditions at TRC Proving Grounds. On-road deployments will take place at various locations across Ohio on public roads.

Testing that takes place on TRC Proving Grounds will comply with the Facility Operating Guidelines (FOG), a set of safety protocols established by TRC to ensure safe operations on the facility. Any test plan that falls outside of the FOG will be submitted to TRC Corporate Administrative Safety Committee (CASC) for review. CASC will provide feedback on the defined test plan and determine if it can be safely carried out and may request modifications prior to approval. These tests do not require a separate SOP.

The project team is responsible for identifying safety scenarios, completing a detailed risk analysis, and designing a safety operational concept. These sections of the SOP must also be reviewed and accepted by Advanced Mobility leadership prior to conducting on-road testing. Milestones will be added to the project schedule for drafting, reviewing, and finalizing the SOP.

TRC's SOP must be reviewed and updated, as appropriate, to reflect changes that impact the test plan. The project team must first consider if the change(s) fall under one of the identified safety scenarios or if the change introduces a new one. The project team then performs a risk analysis to determine if the change(s) introduce additional failure modes. Changes that could potentially impact the SOP include but are not limited to any change to sensor hardware, ADAS software stack, driver interface, sensor software, operating personnel, and the operational design domain (ODD).

It is the responsibility of the project team to ensure that a mitigation strategy developed in Section 3.2 Risk Assessment and enumerated in Table 3-1 has been put in place for all items that have been identified in the risk analysis. The TRC Project Manager is responsible for informing the appropriate stakeholders (at a minimum this includes local law enforcement) of the test plan, including number of vehicles and locations. The outreach to law enforcement will be in coordination with the State of Ohio Highway Patrol.

In addition to a robust SOP, TRC will execute a controlled environment analysis of an ADAS prior to taking it on public roads for testing. The scenarios in this analysis include both basic ADAS functionality and scenarios specific to the ODD. The project team will not deploy an ADAS on the road until it is comfortable with the performance of the vehicle in a controlled environment. This controlled environment testing also gives drivers the much-needed seat time to gain comfort in operating the ADAS.

4.1 Equipment Procurement

The first step to addressing functional safety is to ensure that the underlying equipment has passed quality checks and is ready to be integrated into the system. This has been done by sourcing sensors from reputable companies with quality control checks internal to the supply process. In addition, the supplier/integrator chosen for this project conducts checks on the components as they are integrated into the vehicle to ensure that safety critical sensors are functioning. The vehicle platform is a commercially available vehicle, following industry standards for safety. It was passed through a multipoint inspection upon acceptance to ensure the safety of the underlying vehicle if all automation is disengaged. In addition, Bosch validates the final system level results when performing final calibration of the system.

4.2 Bosch Tractor Release Note Process

This section provides an overview of Bosch's Release Note process. A Release Note must be issued before the truck platooning technology on the two tractors can be operated on public roads. A copy of the final Release Note from Bosch can be found in Appendix C.

This section provides an overview of Bosch's release processes.

1. Testing
    a. An appropriate test plan is created based on the components involved and the purpose of the release
    b. Software is tested throughout development and as it is integrated
    c. When development and calibration are complete, release testing is performed. For the ADS Project this will be the controlled environment testing.
2. Quality gate
    a. The quality gate (QG) checks multiple aspects of the project to determine that the software/hardware being released is safe, secure, and meets legal and customer requirements
    b. Meeting is held with a moderator to review answers to QG questions and make sure supporting evidence is acceptable
    c. QG results are either green, yellow, or red
        i. Green means software is clear to release

ii. Yellow means software is clear to release but there are open points to close after the release
iii. Red means there are issues preventing release
1. In case of a red QG, a risk assessment can be performed and management approval to release can be obtained
d. QG result is recorded, and management approves the QG
3. Release Note
a. The release note indicates what is being released, the allowed usage of the release, and any bugs or issues with the release
b. Bosch has the responsibility for the delivery of the Release Note for the ADS Project

4.3 Pre-Deployment Safety Management

The SMP begins before the vehicle starts the deployment. For prototype systems, it is important that their capabilities are well understood to limit surprises on the road. To this end, extensive controlled environment work is carried out putting the vehicle in scenarios expected on public roads. The result of this creates an understanding of where the system can be safely deployed. In addition, the capabilities will be used to communicate to the driver through an internal TRC driver training program from the Capabilities Report reviewed by Bosch after the CE test results have been shared.

4.3.1 Pre-Deployment Controlled Environment Testing

TRC created a CE Test Plan to develop an understanding of the current abilities and limitations of each tractor. This testing will be done for both tractors, as well as additional testing around capabilities that are not as expected. The CE testing takes a phased and categorical approach towards developing an understanding of the ADAS-equipped vehicles' capabilities to operate safely on public roads. The scheme is structured to expose the ADAS-equipped tractor to progressively complex situations, test the ADAS's response, and inform the safety operator of expected behavior in a controlled environment setting. Such an evaluation will help assess knowledge gaps, functionality gaps, and increase the driver confidence before deployments on public roads and in challenging environments.

The TRC will conduct CE testing to cover the capabilities expected of the two ADAS-equipped tractor systems. The testing will cover two phases of testing. The first will cover both independent SAE Level 1 capabilities (lateral and longitudinal) of the truck, HMI and other visual aids, and the performance of the brake systems and sensors. Phase 2 will cover the platooning performance and the trucks' ability to appropriately engaged, disengage, and safely control speed.

- Initialization and Handover (Engage/Disengage)
- Localization Accuracy
- Waypoint Following
- Lane Keeping (disabled for public road deployment)
- Detect and Respond to Obstacles

Adaptive Cruise Control Categories tested for phase 2 include:

- Engaging Platooning
- Disengaging Platooning
- Continuous Platooning

4.3.2 Controlled Environment Test Plan and Report

The following table provides the CE Test Plan outline for Phases 1 and 2.

Table 4-1. Controlled Environment Test Plan Outline

Phase 1		
Procedure	**Course**	**Runs**
System check	SMARTCenter	15
Braking	Skid Pad	40
Location accuracy	HSTT	12
LKA	HSTT	18
AEB/FCW	SMARTCenter	48
ACC	HSTT	10
Phase 2		
Procedure	**Course**	**Runs**
Platoon formation	HSTT	25
Platoon disengagement	HSTT	40
Platoon steady state	HSTT	9

4.3.3 Deployment Condition Checklist (Bingo Card)

Once CE Testing has concluded and Bosch has reviewed the results during their quality gate, TRC will deploy the tractors on public roads to understand the platoon's performance in the environment they will be driven in. The intent is to provide a summary of deployment, required conditions, data goals, and any notes related to noteworthy potential behaviors or outcomes.

The following table provides the goals and objectives of the public road deployments for the criteria needed to experience.

Table 4-2. Deployment Condition Checklist (Bingo Card)

Deployment Condition Criteria
Determine performance characteristics in various public road scenarios listed below:

▪ Light traffic
▪ Heavy traffic
▪ Activating/disengaging platoon system
▪ Road classes
  • Interstate
  • State Route
  • Local Road
  • City
▪ Atmospheric Conditions
  • Sunny
  • Cloudy
  • Low Sun Angle
  • Dark
  • Mist/slight falling rain/light snow
▪ Criteria
  • Engagement/disengagement time ratio

Deployment 1 – Run 10 times (2 in dark conditions, 2 during rush hour)
▪ US33 540 to Scotts Lawn
Deployment 2
Route A – Run each segment 6 times. ▪ SR33 – 270 (TRC to Columbus) ▪ 270 – 33 (North Columbus to East Columbus around the south) ▪ 33 – 50/32 (SE Columbus – Athens) ▪ 50/32 – 35 (Athens - Jackson) ▪ 35 – 71 (Jackson – Octa) ▪ 71 – 38 (Octa – Bloomingberg) ▪ 38 – 42 (Bloomingberg – London) ▪ 42 – 33 (London – New California) ▪ 33 – TRC (New California – TRC) Route B – Run two times ▪ SR33 – 274 (TRC to Huntsville) ▪ 274 – 75 (Huntsville to Botkins) ▪ 75 – SR33 (Botkins – Wapakoneta) ▪ SR33 – TRC (Wapakoneta – TRC)
Additional Conditions:
Demonstrate that Platooning continues function on public roads
Introduce EASE drivers to platooning system and provide sufficient exposure such that they are comfortable with handoffs. (Target 5 ride-along)
Observe naturalistic behaviors of drivers around the platooning vehicles. (Qualitative)
Understand system reliability when operated for extended periods
Qualitative understanding of changes in fuel efficiency

4.3.3 Unfreeze Software (Post Controlled Environment Testing)

An engineering review will be conducted on any changes to the truck platooning system's configuration, hardware, or other aspects after the completion of the CE testing. If any changes are determined to potentially cause the vehicle to react less conservatively or the outcome is not well known, the system will require further CE testing before continued use on public roads. In the CE testing, only the aspects of the vehicle affected by the change will require testing. For example, if the longitudinal platooning control is updated to allow for closer following (not affecting the ACC or the engage/disengage functionality) then only the steady state platooning testing will need to be completed again.

4.3.4 Pre-Trip Checklist

Routine maintenance will be done on the vehicle to ensure it continues to operate at the expected level. In addition, a pre-trip checklist (Appendix D) will be carried out before taking the vehicle on the public road with truck platooning active, including the following examples: tire condition, chicken lights functioning. TRC will generate a truck platooning-oriented pre-trip checklist for its use on public road deployments. This checklist will be shared with the host fleet for its review and modification to its existing SOP's pre-trip checklist.

4.3.5 TRC Truck Platooning Guidelines

From the environmental, operational, and tractor behavior TRC detected with their time in testing at TRC with the tractors, limitations were put into effect to assist the TRC drivers on of the tractors for public deployments. These suggestions will be shared with the host fleet for its review and modification to their operations manual.

The following table provides the limitations TRC practiced throughout their public road deployment.

Table 4-3. Truck Platooning Guidelines

Truck Platooning Guidelines
Environmental Limitations of Engagement
Adverse Weather 1. Wet Roads – Shift follow distance to 3 seconds. 2. Icy Conditions – Platooning system should not be engaged. 3. Visibility – Platooning system should not be activated when visibility is below ¼ mile or less. (14 second reaction time at 65mph)
Traffic 1. Platooning system should not be activated in heavy traffic scenarios. 2. Driver needs to be ready to take back control in case sudden heavy traffic may come up.
Construction 1. Platooning system should not be activated in construction zones.
Highway 1. Platooning system should only be engaged on public highways where posted speed limits are above 45mph. 2. Disengage System when crossing railroad tracks. 3. Do not activate Platooning system when following School buses.

Truck Platooning Guidelines
Traffic Light 1. When approaching a traffic light while the platooning system is engaged, communication between lead and follow truck must be used to disengage system.
Hill Ascents 1. If the tractors are approaching a large hill ascent, the follow tractor's distance interval may increase. If the tractor reaches more than a 4.0 interval distance, the tractor may disengage. If the operator anticipates the hill may cause the interval distance to be close to the 4.0 second drop, the operator should disengage the system and reactivate once they have ascended the hill.
Tractor Engagement Limitation
Speed matching 1. There should not be a large variance in speed between lead and following tractor when engaging the platooning system. Platooning system should be engaged when vehicles' speed is different by <10mph. 2. RAPID BRAKE DURING ENGAGEMENT – To help mitigate the occurrence of a hard brake situation for the follow truck during the engagement of platoon, it is best practice for the follow tractor to activate the system when the follow tractors speed is EQUAL or LESS than the lead tractor's speed. There have been observed occurrences of the follow tractor engaging brakes when entering the platoon system and both vehicles are "activated". To help ensure this rapid brake engagement does not occur, lowering the follow truck's speed to engage the system has minimized this behavior from occurring.
Vehicle Speed 1. Vehicle must be traveling above 40mph to activate. 2. If traveling in a 70mph zone, lead truck should be going 65mph until both tractors are engaged in a steady state.
Road Lanes 1. Vehicles must be in same lane to activate 2. Operator is always in control of steering. (No LKAS [Lane Keeping Assist System])
Tractor Faults (DTC's) 1. Platooning system should not be engaged if there are any faults displayed in the dashboard
Communication 2 1. If using EARTEC headsets, batteries must be swapped after 4 hours of use 2. If using the EARTEC headsets, communication range is ½ mile. Anything beyond must use CB transmission.
Operational Conditions
Trailer Configuration 1. Lead Trailer needs to have a heavier trailer load. 2. White Truck (Jerry) must always be the lead vehicle in platooning. 3. Red Truck (Tom) must always be the follow vehicle in the platoon.

4.4 Operator Training and Deployment

Understanding the ADAS-equipped tractor's capabilities will only be effective if there are properly trained drivers and operators who can enable and disable the system in the correct circumstances and take control when necessary. This training of drivers to operate the truck platooning features is a requirement of this SMP for public road operations by the project deployment partners (TRC and host fleet). Also, the host fleet and ODOT contract will require such training for host fleet drivers. To achieve a safe operation of the vehicle, all drivers will be trained. A driver training plan (Appendix E) will be developed for this very purpose. Its goal is to provide drivers with an understanding of current automation capabilities and training to improve attention and takeover capabilities. This includes an in-depth understanding of the software and its limitations.

4.4.1 Driver Training

Bosch will lead the driver training from the technical perspective with TRC support on-site. This training will be conducted by Bosch to instruct system operating guidelines. During this training, the TRC drivers will first witness platoon creation from both the lead and follow vehicle, then demonstrate understanding from the driver's seat (again from both the lead and follow vehicle). After this is completed, TRC will present ADS operators with safety guidelines, which will go over the importance of staying engaged in the driving task, especially for prototype systems. Once all criteria has been met in the driver training checklist (Appendix F) and the driver's feel comfortable with operating the platooning system, a checklist will be presented for the drivers with their signatures to confirm they have driven in all scenarios indicated on the driver training checklist.

4.4.2 Host Fleet Drivers

TRC will train the host fleet drivers according to the project driver training plan. This training is a requirement in the Bosch Release Note as well as in the host fleet contract with ODOT (as reference in the ODOT RFP No. 554-23). This driver training will take place before the two ADAS-equipped tractors are delivered to the host fleet. Further, only trained drivers may operate the two ADAS-equipped tractors during the host fleet deployment phase of the ADS Project in truck platooning mode.

4.5 Deployment Plan

4.5.1 Incident Reporting

TRC utilizes corrective action management (CAM) to report all appropriate incidents, both on TRC Proving Grounds and off. All employees are accountable for reporting incidents of various nature including safety risks. Should an incident occur, employees must report the incident to their direct supervisor and provide the details needed to complete an incident report.

Supervisors are responsible for submitting incidents into the CAM system. The intent of the CAM process is to identify improvements that can be made to prevent or reduce the chance of incident recurrence. Contacting emergency personnel always takes precedence when an incident involves injury or property damage.

4.5.2 Operational Design Domain

The final ODD is included as **Figure 4-1** in this version of the SMP provided by Bosch with input from TRC. Nothing in the SMP will override the guidance in the ODD provided by Bosch.

Figure 4-1. Operational Design Domain (ODD) Checklist

ODD Checklist	Platooning	
	y/n	Comments
Physical Infrastructure		
Roadway types		
Divided highway	y	
Undivided highway	y	
Arterial	y	
Urban	n	
Rural	y	
Parking	n	
Bridges	y	
Multi-lane/single-lane	y	
Managed lanes (HOV, HOT, etc.)	n	
On-off ramps	n	
Emergency evacuation routes	n	
One way	n	Not including divided roads/highways
Private roads	n	
Runaway truck ramps	n	
Roads with bike lanes	n	
Reversible lanes	n	
Intersection types		
Signal	n	
U-turn	n	
4-way	n	
3-way	n	
2-way	n	
Stop sign	n	
interstate interchanges (cloverleafs, etc.)	n	
Roundabout	n	
Merged lanes	y	
Interstate entrances/ exits	n	
Left turn across traffic	n	
Right turn	n	
Multiple turn lane	n	
Crosswalk	n	
Toll plaza	n	
Railroad crossing	n	
Roadway surface		
Asphalt	y	
Concrete	y	
Mixed	y	
Grating	n	
Brick	n	
Dirt	n	
Gravel	n	
Scraped road	n	
Partially occluded	n	
Speed bumps	n	
Potholes	n	
Grass	n	
other	n	
Roadway edges & Markings		
Lane markers	y	
Temporarily lane markers	y	
Shoulder (paved or gravel)	y	
Shoulder (grass)	y	
Concrete barriers	y	
Grating	y	
Rails	y	
Curb	y	
Cones	n	

ODD Checklist	Platooning	
	y/n	Comments
Roadway Geometry		
Straightaways	y	
Curves	y	The radar will sometimes misidentify the lead tractor during curves. The driver will receiver an audio warning if this is the case and should disengage the system. If there is no warning then operation through curves is fine
Hills (Slope)	y	The system sometimes has issues maintaining velocity when ascending hills. In this case the system should be disengaged and reengaged after the ascent is complete.
Lateral crests, cross slope	y	
Corners (Regular, Blind)	n	
Negative obstacles, local sinks	n	
Local peaks	y	
Lane width	N/A	
Other		
Operation Constraints		
Human Interactions		
see actors, roles and interfaces in Context-Definition		
Tractor		
Tractor wear status	N/A	Specific Demonstration Tractor
Tractor health status	N/A	
Tractor pitch - Frame	N/A	
Tractor pitch - Cabin	N/A	
Tractor roll - Frame	N/A	
Tractor roll - Cabin	N/A	
Tractor dirt (show, ice, dust, dirt)	N/A	
Tractor cleaning	N/A	
Tractor mounting arrangements	N/A	
Tractor calibration interferences	N/A	
Trailer		
Trailer wear status	y	Good condition trailer with integrated ABS
Trailer health status	y	
Trailer load type (swapping, livestock, dangerous goods, ...)	y	No liquid loads or large dynamic loads (unsecured freight)
Trailer load (mass, cog, ...)	y	Evenly distributed load expected. When different, lighter load should be in the follow tractor.
Trailer load fixation (liability)	y	
Speed		
Minimum Speed Limit	y	37mph
Maximum Speed Limit	y	65mph
Maximum Speed Limit Ego	N/A	
Night Speed Limit	y	65mph
Expected speed range of others	N/A	
Driving direction	N/A	
Other	N/A	
Traffic Conditions		
Traffic density	y	Driver discretion, with congestion driver care is required. System should be disengaged if either driver has concerns
Accident Emergency vehicle	n	
Construction	n	
Closed road (section)	n	
Special event	n	
Objects		
Signage		
Signs (e.g., stop, yield, pedestrian, railroad, school zone, etc.)	N/A	Vehicle does not have sign detection
Traffic Signals (regular, flashing, school zone, fire dept. zone)	N/A	
Crosswalks	N/A	
Railroad crossing	N/A	
Stopped buses	N/A	
Construction signage	N/A	
First responder signals	N/A	
Distress signals	N/A	
Roadway user signals	N/A	
Hand signals	N/A	
Other		

ODD Checklist	Platooning	
	y/n	Comments
Roadway Users		
Vehicle types (cars, light trucks, large trucks, buses, motorcycles, wide-load, emergency vehicles, construction or farming equipment, horse-drawn carriages/buggies)	y	Standard highway traffic is okay.
Stopped vehicles	n	
Other automated vehicles	n	
Pedestrians	n	
Cyclists	n	
Other		
Non-Roadway Users Obstacles		
Animals (e.g., dogs, deer, etc.)	n	
Debris (e.g., pieces of tire, trash, ladders)	n	
Lost cargo	n	
Other		
Environmental Conditions		
Weather		
Wind	y	
Rain	y	System should be disengaged if visibility is below a quarter mile or if standing water on roads
Snow	y	System should be disengaged if visibility is below a quarter mile or if any snow accumulation on roads.
Sleet	n	
Temperature Chassis	N/A	
Temperature AD active	N/A	
UV radiation	N/A	
Other		
Weather-Induced Roadway Conditions		
min µ_friction homogeneous		
max µ_friction split	n	
Standing Water	n	
Flooded Roadways	n	
Icy Roads	n	
Snow on Road	n	
Other		
Particulate Matter		
Fog	y	As long as visibility is above a quarter mile
Smoke	n	
Smog	n	
Dust/ Dirt	n	
Mud	n	
Spray	n	
Other		
Illumination		
Day (sun: Overhead, Back-lighting and Front-lighting)	y	
Dawn	y	
Dusk	y	
Night	y	
Street lights	y	
Headlights (Regular & High-Beam)	y	
Oncoming vehicle lights (Overhead Lighting, Back-lighting & Front-lighting)	y	
Other		
Connectivity		
Vehicles		
V2V	y	
V2I	n	
V2N	n	
Wired connection	n	
Emergency Vehicles	n	
Connection Quality	n	
Predictive Quality of Service	n	
Other		

ODD Checklist	Platooning	
	y/n	Comments
Remote Fleet Management System		
Does the ADS require an operations center?	n	
Does remote operation expand ODD	N/A	
Does remote operation reduce ODD	N/A	
Does remote operation support fault handling?	N/A	
Other		
Infrastructure Sensors		
Work zone alerts	N/A	
Vulnerable road user	N/A	
Routing and incident management	N/A	
Other		
Digital Infrastructure		
GNSS	y	GNSS reception required for timing and positioning
3D-Maps	N/A	
Pothole Locations	N/A	
Weather Data	N/A	
Infrastructure Data	N/A	
Traffic data (density, accidents, ...)	N/A	
Other		
Zones		
Geofencing		
CBDs (Central Business District)	N/A	
School Campuses	N/A	
Retirement Communities	N/A	
Fixed Route	N/A	
Restricted (e.g. Hub)	N/A	
Traffic Management Zones		
Temporary Closures	N/A	
Dynamic Traffic Signs	N/A	
Variable Speed Limits	N/A	
Temporary Lane Marking	N/A	
Non-Existent Lane Marking	N/A	
Human-Directed Traffic	N/A	
Loading and Unloading Zones	N/A	
Dynamic speed limit	N/A	
Erratic pedestrian	N/A	
Vehicular behaviors	N/A	
Other		
Regions/States		
Legal/Regulatory	y	Limited to State or Federal Regulations. Current approval in Ohio. Additional States must be contacted and given permission before operating.
Enforcement Considerations	N/A	
Tort	N/A	
Other		
Interference Zones		
Tunnels	n	Underpass is okay but extended tunnels will cause issues with GPS accuracy
Truck weight stations	n	
Parking Garage	n	
Dense Foliage	n	
Limited GPS	n	
Atmospheric Conditions	n	
Other		

4.5.3 Driver Responsibility

The truck platooning system is still a prototype system. Even if it was fully realized, it would still be a Level 2 system and therefore requires the driver to be constantly engaged in the driving task. The driver is responsible for monitoring the roadway and taking action before a potential collision could take place. In general, the driver is responsible for the conduct of the tractor regardless of the ADAS technology engagement. The driver will be a professional driver with direct experience in operating the vehicle. The driver will monitor the vehicle for drifting toward lane lines, sudden motion changes, and potential impacts with other vehicles, vulnerable road users, or objects. However, as the lateral control of the vehicle is extremely limited, this ADAS feature should be used sparingly and only as an assistance/avoidance tool, not as the primary method of steering the trucks. In addition, the driver will monitor the vehicle's surroundings in case intervention is required. Finally, the driver will ensure the vehicle stays inside the ODD in the SMP.

4.5.4 Platoon Engagement/Disengagement

The driver is responsible for engaging the system. The drivers will work in conjunction when the platooning system is being engaged to ensure there will not be any conflicts with the surrounding traffic. If one sees a reason to disengage the system, they will do so in coordination with the other driver, if time permits, to reduce the risk of any sudden conflict with the other truck or surrounding traffic.

4.5.5 Host Fleet Responsibilities

DriveOhio/ODOT will use their procurement system to select a host fleet to operate the two ADAS tractors in-revenue service. The procurement system included a RFI as well as a competitive RFP. A host fleet was selected via the RFP driven proposal from the host fleet. The proposal process included an interview. The host fleet has mandatory requirements as listed in the RFP. Also, a contract between ODOT and the host fleet will reference the RFP requirements. For reference, the ODOT RFP is number 554-23 and the selection process is documented by ODOT procurement office. The ODOT/selected host fleet contract will reference this SMP, specifically the Bosch technology Release Note and the risk assessment processes, as well as the ODD. The ODD in this SMP include the technology limitations of use and conditions of use of the Bosch technology on the two tractors while in operations by the host fleet. The SMP and ODD are important to the limits of use for the tractor technology by the host fleet in operations and the training requirements of the host fleet professional drivers to operate the tractor technology. This training requirement is part of the ODOT/host fleet contract. In general, the host fleet is responsible for the use of the two ADAS-equipped tractors while in their operations. The host fleet will identify truck platooning route(s) and DriveOhio/ODOT will review/approve the route(s). The operations of the two ADAS-equipped tractor technology on these truck platooning routes must follow the SMP and ODD limitations, and other related requirements in the ODOT/host fleet contract. Also, the truck platooning routes will be subject to a law enforcement stakeholder meeting(s) involving the State of Ohio Highway Patrol. The purpose of the meeting is to organize all levels of law enforcement along the truck platooning route. Lastly, the Highway Patrol issued a Truck Platooning Operating Memo to the host fleet which provides information about the truck platooning technology for any law enforcement to review while in operations on Ohio public roads.

The ODD, driver training requirement, and the Truck Platooning Operating Memo applies to any truck platooning technology testing by TRC drivers on Ohio public roads.

4.5.6 Platoon Indication Exterior Lighting (Chicken Lights)

Each of the tractors has been outfitted with exterior purple indication lights, a.k.a. “chicken lights” to indicate when platoon mode is engaged. Due to the decreased following distance of the tractors in platoon mode, exterior indication lights provide a visual reference to law enforcement that platoon mode is activated. Ohio State Highway Patrol has requested the color of the indication lights to be purple, and that two indication lights are located on the exterior of each tractor on the left and right sides. Consideration has gone into the brightness of the indication lights as to not create an obstruction to passing vehicles in daylight or dark conditions but still be visible in bright conditions. Currently, the brightness of the lights is based on guidance from Federal Highway Administration. The indication lights will automatically illuminate when the driver activates platoon mode and turn-off when platoon mode disengages. The indication lights can be manually activated on a user control panel as part of the driver pre-trip checklist before deployment or road use but will not be manually activated once the tractor is in motion.

Figure 4-2. V.1 Platoon Lights in Overcast Conditions

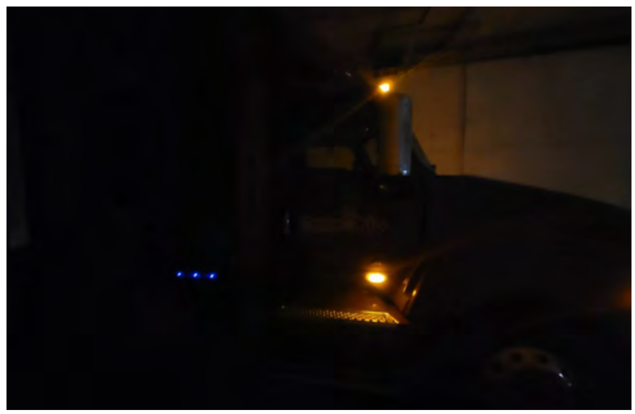


Figure 4-3. V.2 Platoon Lights in Night Conditions

Section 5
Coordination with Other Tasks

The SMP is not a standalone document, as other reference project documentation and project partner documents provides the information for the risk analysis, and the outputs and mitigations needed to populate other documents in the project, and vehicle operating guidance. This section identifies the coordination required with other tasks. The documents produced for the below tasks are subject to revisions as the project develops.

5.1 Concept of Operations

Safety scenarios in this SMP follow the ConOps, operational concept, and use cases developed for the tractor deployment. The ConOps lists the user needs, applications to be deployed, and operational practices to be followed for the deployment. Section 4, Safety Operational Plan was developed in coordination with the proposed operational practices described in these conceptual documents for each project.

5.2 Deployment System Requirements

The System Requirements created for the ADS tractor deployment will identify and specify the requirements following established guidance such as those in the Federal Highway Administration's Systems Engineering for ITS. The requirements will be based on the user needs and system concept developed and documented in the ConOps. The Institute of Electrical and Electronics Engineers (IEEE) Standard 1233-1998, the IEEE Guide for Developing System Requirements Specifications, will be used as the general guide for documentation. Although the IEEE guidance allows significant flexibility in the structuring of requirements, the specification will use the common categories of functional, interface, performance, security, data, and reliability requirements.

5.3 Data Management Plan

While the SMP outlines high-level mitigation strategies for the data storing risks identified, the DMP developed for the ADS Project describes how data will be collected, managed, integrated, and disseminated before, during, and after the tractor deployment. The DMP also provides detailed protection and mitigation for data risks identified to protect the privacy of the users and ensure secure operations. The DPP and DMP work to ensure that data privacy and operations are secure.

5.4 Data Privacy Plan

The DPP created for the ADS Project provides guidance material regarding security and privacy for the ADS Project deployments. The document is developed based on identifying the impacts of security breaches regarding confidentiality, integrity, and availability along with potential threats. The safety scenarios, as well as safety operational concept, were developed to protect the privacy of users, ensure secure operations, and eliminate the impact of security breaches.

5.5 Human Use Approval Summary

The Human Use Approval Summary aims to document the efforts made to ensure the protection of personal information, which is the purview of the DPP, and human safety which includes the mitigation strategies discussed in this SMP. In the tractor deployment in this project, there is no personally identifiable information (PII). ODOT staff and past practice determined that incidental video of pedestrians near the vehicle is not PII. Host fleet and TRC drivers and other TRC staff in the tractor deployment are employees of the host fleet and TRC, respectively, and are exempt from Institutional Review Board (IRB) requirements. No data about the driver, either personal data or video, is being collected. Documentation submitted to the IRB at the University of Cincinnati noted that a consent form is not required for those host fleet and TRC employees. Thus, although a protocol document was submitted to the IRB by the project, no human use approval is required for the truck deployment.

5.6 Driver Training Plan

TRC/Bosch have developed the Driver Training Plan for host fleet and TRC employees involved in the deployment, and it divides the efforts among three objectives. For end-users, like the tractor drivers, the emphasis will be on developing a level of comfort and understanding of the operation and messaging provided to them in-vehicle. Drivers may not be aware of the potential safety scenarios and the actions they are expected to take during emergency situations. Therefore, the mitigation strategies from the SMP will be included as part of the training plan as a key to prevent personnel injury and eliminate the potential impacts when safety risk scenarios happen. An end-user training plan will be developed, consistent with the Human Use Approval Summary that would include driver inputs from controlled environment and field deployment tests.

5.7 Stakeholder Outreach Plan

Communications and engagement plan prepared by the project team include driver training and stakeholder education, as well as the identified stakeholders for the ADS Project. These activities identify the participant roles and responsibilities taken during the deployment, their actions, and training requirements. Communications and outreach will be consistent with the actions described in the SMP to reduce the likelihood and potential impact of each safety scenario. A second set of stakeholders is law enforcement. Specific law enforcement stakeholder meetings will be determined to cover the specific routes for all truck platooning operations, including TRC drivers and host fleet drivers. The project team will coordinate with the State of Ohio Highway Patrol to conduct these educational meetings for law enforcement.

5.8 Interface Control Document

The ICD developed for the ADS-equipped tractor deployment refers to the SMP to make sure all the safety risks listed in this plan are addressed while designing and testing the system and applications developed in this deployment.

Section 6

Summary/Conclusions

The SMP provides guidance material about the identification of safety scenarios, risk mitigation, limitations of use and other guidance for the project deployment partners for the tractor deployments. The plan identifies the safety scenarios at deployment level, assesses the level of risk for each scenario, and provides a safety operational concept for high/medium risk scenarios. Safety stakeholders for each project were identified and coordination with law enforcement was incorporated in the SMP.

This document will help to understand the safety aspects of operating ADAS-equipped tractors in public roads in Ohio, as well as the incident reporting requested by NHTSA and State of Ohio. Further, it is expected that this is a living document that will be updated based on the test results and early deployment actions, ultimately feeding back into the risk mitigations and driver training plan updates.

Additional conclusions and next steps regarding safety management include:

- The project team will provide guidance to the deployment team and continue to follow all scenarios. The purpose will be to document verification of safety-related requirements and to coordinate safety-related activities of all stakeholders.
- The driver training will advise participants of the safety problems that might arise and how to get aid, if needed.
- While the ConOps and System Requirements documents are finalized for this deployment, refined analysis may lead to more safety scenarios being identified. They will be rated and tracked along with those already identified. Some of the safety scenarios will be addressed by writing safety requirements and verifying designs to those requirements. They will be tracked through design and development phases of the deployment. Other hazards will require ongoing safety management through the duration of the deployment phase.
- If development of the ADAS-equipped tractor technology is unfrozen after the completion of the CE tests, the project team will reevaluate and determine if additional CE testing is required. If so, the tractors need to undergo such CE testing before operating on public roads.
- All drivers operating ADS Project truck platooning technology on Ohio public roads must be trained using the ADS Project training plan.
- The host fleet must understand, agree to, and incorporate into their SOP the stated limitation of the ADAS-equipped technology as documented in this SMP, as well as referenced in this SMP.

Appendix A

Truck Platooning White Paper

Automated Driving System (ADS) Project

In September 2019, the Ohio Department of Transportation (ODOT) was awarded a grant to test autonomous vehicle technology on rural Ohio roadways. DriveOhio, Ohio's forward facing government entity for autonomous vehicles and a subsidiary of ODOT, is overseeing this project and bringing together the necessary stakeholders. In late 2022 and early 2023, two class 8 semi tractors will begin operating on Ohio roadways with Level 2 autonomous technology. The technology being installed on these vehicles is provided by Bosch and installed under the project manager of CDM Smith.

In Level 2 technology, the human driver: supervises the driving automation system and intervenes as necessary to maintain operation of the vehicle; determines whether/when engagement and disengagement of driving automation is appropriate; and immediately performs the entire driving task when required or desired.[1] It is important to note that Level 2 automation includes a lesser degree of automation technology and the human driver is responsible for the vehicle operations. Level 2 automation can turn the vehicle, accelerate and decelerate. The system will disengage when requested by the human driver.

The vehicles also have platooning capabilities that will be tested. Vehicle platooning is the linking of two or more vehicles using vehicle-to-vehicle communication technology[2]. The platooning system being used is also categorized as Level 2 technology. When the vehicles are actively platooning, a purple LED light, located on both sides of the cab, will be illuminated. The two platooning trucks being used can operate at Level 2 autonomous vehicle mode independently or together.

During platooning, the trucks will be following each other at a distance of 1.2 - 1.5 seconds. Under Ohio Revised Code, section 4511.34 requires the distance between vehicles to be, "reasonable and prudent, having due regard for the speed of the vehicle." A proper distance between vehicles is critical to allow for driver perception/reaction time. These vehicles will be communicating directly with each other, which mitigates the need for a perception/reaction time. When the lead vehicle applies the brakes, a signal is sent to the trailing vehicle and the brakes are applied moments later.

[1] SAE J3016 – Surface Vehicle Recommended Practice – April 2021 – Page 28
[2] AAMA – Safe Testing and Deployment of Vehicles Equipped with Automated Driving Systems Guidelines – Edition 2 – Page 79 – Section 7.5 Platooning Vehicles

Automated Driving System (ADS) Project

The vehicles will test on dedicated routes starting in October 2022 and will be operated by drivers from the Transportation Research Center (TRC). TRC drivers will train drivers from EASE Logistics, as the trucks will be transferred to EASE to be introduced into their normal trucking operations. EASE will take possession of the trucks at the end of calendar year 2022. EASE will determine how the trucks will be used, and will report the data of operations back to the project management team from DriveOhio, CDM Smith, and Bosch. The trucks will be operated on public roadways through March of 2024.

Any law enforcement interaction with these vehicles should be reported to DriveOhio on their incident reporting form at https://bit.ly/DriveOhio-ADS-Reporting. Questions for DriveOhio about this project can be directed to ruralavdata@drive.ohio.gov. These contacts, whether in an officer-initiated traffic stop, crash investigation, or consensual encounter are critical to understanding the needs of law enforcement and will help to shape future trainings. If officers have immediate questions, please contact Staff Lieutenant Chris Kinn of the Ohio State Highway Patrol – Office of Field Operations at 614-420-4385 or cjkinn@dps.ohio.gov.

Appendix B

Automated Vehicle Law Enforcement Reporting Form

OHIO DEPARTMENT OF TRANSPORTATION

DriveOhio is working with industry and public sector.

As this new technology is tested and driven on Ohio's public roadway, we acknowledge that there will be interactions between automated vehicles and law enforcement. This form and database will gather and store information to help our DriveOhio team understand trends or concerns, then work better with industry and public sector.

You are reporting this type of event:*

- ☐ crash
- ☐ traffic stop
- ☐ consensual encounter

When did the event occur: Date/Time*

[ ] [ ] [ ]

[ ] : [ ]

Where did the event take place (what address, roadway milemarker, or intersection):*

[ ]

County where the event took place*

ADAMS

Driver/Operator Name*

First Name

Last Name

Vehicle License State/Number*

Describe the circumstances of the event, the interaction with the automated vehicle and the driver:*

Law enforcement officer who had the interaction

Name*

First Name

Last Name

Role/Title

Agency/Employer*

Phone

Email*

Submit Form

The Ohio Department of Transportation
1980 West Broad Street, Columbus Ohio 43223
Mike DeWine, Governor | Jack Marchbanks, Ph.D., ODOT Director | Feedback | Ohio.gov

Appendix C

Bosch Release Note

Software Release Recommendation

Project / Product information			
BE-061753 DriveOhio ADS Grant Platooning Study			
Product:	Platooning System	Safety-Level:	QM
Bosch/BEG-Identifier: (e.g. SW name, version)	Limited Road Release		
Customer-Identifier: (e.g. SW name, version)	Limited Road Release		
Changes to previous version	prev. version:	N/A	
	Delivered on:	N/A	
Description of changes / functional content: Initial system release			
Additional release documents			
Notice_extract_v2xd_v1_0_1130			
Status of the delivery product, range of application			
All planned requirements are implemented	YES ☒ NO ☐	Remarks:	
Planned Verification and Validation has been finished	YES ☒ NO ☐	Remarks: Validation based on CE Test Report	
Verification and Validation results without release relevant findings	YES ☒ NO ☐	Remarks:	
Open Source License: Open Source in Product - see additional release documents 3rd party SW / External SW: 3rd party software is contained (dSpace RTI and related libraries)			

Recommended use

The delivered software is recommended to be used for following intended-use:

RT_4 - Road General (with Limitations/Restrictions)

This recommendation is only provided for BEG developments – SW parts provided by customer are not considered.

Operational environment:

Limited use to special target environments (e.g. vehicle variant, hardware variant, ...)

Additional hints:

Release approved for use on public roads by trained drivers in accordance with the restrictions and prerequisites defined in:

Concept of Operations
Safety Management Plan
Data Management Plan
ODD Checklist
Interface Control Document
Driver Training Plan

Risk

Software may contain untested parts. Unexpected behavior or critical situations may occur. Environment of product / product user must be able to handle malfunctions in a safe way (e.g. trained driver on public roads).

Known problems leading to additional risks/limitations/restrictions not covered in Safety Concept and corresponding Safety Measures

Nr.	Description	Evaluation / Hint / Measure

Miscellaneous

Additional hints:

Other relevant documents:

Release Recommendation

Based on the results of verification and validation activities based on customer requirements, BEG recommends this software for release according to the above-named intended use. The final release must be granted by the customer.

Responsible for Release Recommendation
Test Manager is responsible for Release Recommendation. Project Management Team Representative can take over responsibility in case of intermediate SW integration (lab usage only).

Name, Department:	Jordan Hughes-Buckley (BEG/PJ-OSK-NA)	Date:	1/25/2023
Signature:	pki, BOSCH, US, J, O, Jordan.HughesBuckley	Digitally signed by pki, BOSCH, US, J, O, Jordan.HughesBuckley Date: 2023.01.25 16:21:16 -05'00'	

Appendix D

TRC Pre-Trip Checklist for Platooning

TRC

ADS Grant: DATA Truck Pre-Trip Inspection Checklist

Prior to operating the International A26 Semi equipped with Bosch's technology for public road platooning, the following pre-trip checklist must be completed to ensure all systems are operating effectively.

1. _____ First complete a vehicle inspection according to the North American Standard Inspection Procedure (NASTP) using the provided inspection pad.

Next, complete an inspection of the platooning system components according by the following:

2. _____ Visually inspect the following for any damage, securement, and wiring issues
   a._____ Radar
   b._____ Platooning Lights
   c._____ Steering Assist motor
3. _____ Open side compartment and power it on the system on using the master power switch
4. _____ Turn the platooning lights on using the test switch
   a._____ Inspect both platooning lights to ensure that they are functional when energized
   b._____ Turn off platoon light test switch.

Once in the truck:

5. _____ Start the vehicle
6. _____ Inspect the following components for loose connections.
   a._____ RJ45 connectors
   b._____ Plug connectors
   c._____ Goldbox Power Connector
   d._____ Cellular Connections
7. _____ Follow the startup procedure specific to the vehicle you are operating.

**If any of the following items cannot be checked-off during the inspection, DO NOT attempt to activate platoon mode on public roads. Please notify your supervisor for further assistance.*

Driver Signature: ____ Date: ______________

The material covered in this document are suggested practices that TRC incorporates into their Controlled Environment and Deployment on the ADS Grant Project. These are not set standards or requirements and the purpose of this document is meant to be a guide. Material is subject to change as TRC progresses through CE Testing and Deployment.

TRC

ADS Grant: DATA Truck Pre-Trip Work Instruction

Prior to operating the International A26 Semi equipped with Bosch's technology for public road platooning, the following workflow instruction has been created to assist in the pre-trip checklist.

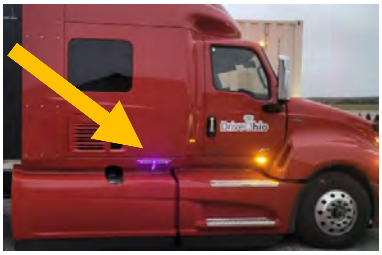
1. First complete a vehicle inspection according to the North American Standard Inspection Procedure (NASTP) using the provided inspection pad.

Example can be found at: *https://www.opp.psu.edu/sites/opp/files/pre-trip_inspection_form.pdf*

Next, complete an inspection of the platooning system components according by the following:

2. Visually inspect the following for any damage, securement, and wiring issues
    a. Radar - Check for secure mounting and that all wires are securely attached. Make sure nothing is cracked, bent, broken, frayed, or loosely connected.

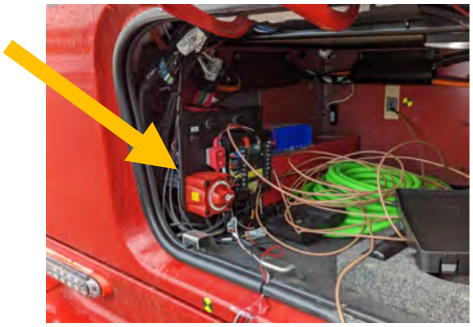
    b. Platooning Lights - Check to see that it is securely mounted and not cracked, bent, or broken and all wires are securely attached.



    c. Steering Assist motor (under hood on driver's side) Check to see that it is securely mounted and not cracked, bent, or broken.

The material covered in this document are suggested practices that TRC incorporates into their Controlled Environment and Deployment on the ADS Grant Project. These are not set standards or requirements and the purpose of this document is meant to be a guide. Material is subject to change as TRC progresses through CE Testing and Deployment.

3. Open side compartment and power it on the system on using the master power switch



4. Turn the platooning lights on.
    a. Turn on Platoon Lights from the SPod in the driver compartment. The icon will turn red once the lights are on.

    b. Inspect both platooning lights to ensure that they are functional when energized. They should illuminate purple when the SPOD icon has been selected.

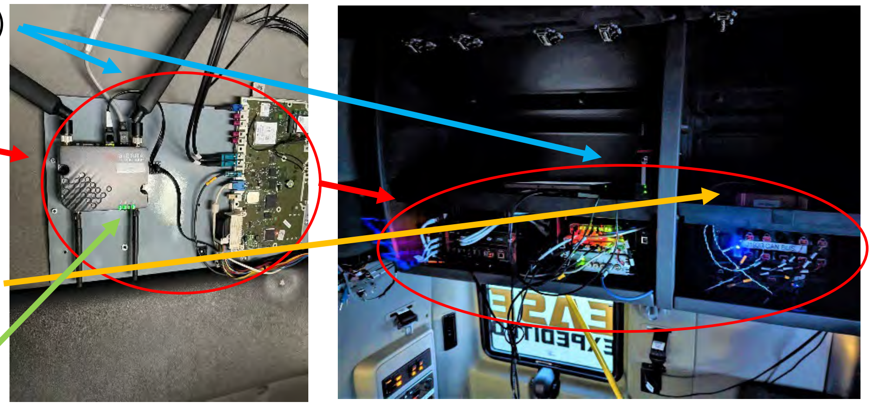
    c. Turn off platoon light test switch on SPod. Icon will turn gray.

**If the platoon icon light is left on (RED) the platoon lights will always stay on. It is important to turn the switch off (Gray icon) to make sure the LED's only activate when the system is turned on from the HMI.*

The material covered in this document are suggested practices that TRC incorporates into their Controlled Environment and Deployment on the ADS Grant Project. These are not set standards or requirements and the purpose of this document is meant to be a guide. Material is subject to change as TRC progresses through CE Testing and Deployment.

Once in the truck:

5. Start the vehicle
6. Inspect the following components for loose connections.
    a. RJ45 connectors (Ethernet)
    b. Plug connectors
    c. Goldbox Power Connector
    d. Cellular Connections



7. Follow the startup procedure specific to the vehicle you are operating.

**If any of the following items are inoperable or damaged during the inspection, DO NOT attempt to activate platoon mode on public roads. Please notify your supervisor for further assistance*

Appendix E

Driver Training Plan

Driver Training

Introduction

- Overview of SAE Levels
  - What do these tell you
  - What don't these tell you
    - Capability
- Expectations for vehicle's capability
- What is the makeup of an ADS? (Components)
- ADS feature user interface, activation /deactivation procedures, and potential failure modes
- Law enforcement and permissions needed

Goal

Provide drivers with an understanding of current automation capabilities and training to improve attention and takeover capabilities.

Methodology

CHAT methodology (Check, Assess, Takeover)

Pre-Requisite Courses

Level 2 Driver Training (See Appendix A: Level 2 Driver Training Requirements)

Classroom Curriculum (see presentation)

Overview including SAE levels

- Expectations of what vehicles can do
  - Set low expectations for testing
- Components of an ADS
- Fundamentals of automation (How can it localize, detect surroundings, and determine what to do)
- Check, Assess, and Takeover
  - Constantly be monitoring surroundings and know take over paths
  - When a take-over should occur
  - Potential reasons for takeover (Unexpected braking, swerve/veering toward something, imminent collision, law violation)
- Videos and images of ADS and human error

Track-based Driving

- **Longitudinal AEB Takeover** (2-4 Hours)
  - System Response/No Response – Static Car Target
  - System Response/No Response – Static Pedestrian Target
  - System Response Insufficient – Static Car Target

- System Response Insufficient – Static Pedestrian Target

- **Lateral Control Takeover** (2-4 Hours)
  - System Response/No Response – Curve Following
  - System Fails to Decelerate Sufficiently to Safely Follow Curve
  - System Improperly Drifts out of Lane of Travel – Straight Road
  - System Improperly Drifts out of Lane of Travel – Curved Road
- **Drive-By-Wire Automated System** (2-4 Hours)
  - Lap showing how to engage/disengage vehicle
  - Lap with sudden brake event
  - Lap with sudden lateral event
  - Lap with sudden acceleration
  - Lap with rule violation
  - Lap with sudden ADS disengagement

Longitudinal AEB Takeover

Scenario #1: System Response/No Response – Static Car Target

- Set up strikeable static car target in center of lane of travel.
- Enable Subject Vehicle's collision avoidance system (either vehicle's stock CMBS or installed control system)
- Manually drive SV in center of lane at 25 mph toward rear of target
- Allow SV's system to perform AEB stop in response to target
- Repeat several times until trainee is comfortable with maneuver (at least 3)
  - If using stock CMBS, cycle vehicle's ignition in between runs to avoid tripping a system error from performing too many AEB stops consecutively
- Turn off the CMBS system
- Manually drive SV in center of lane at 25 mph toward rear of target
- Wait until the system would have provided an alert or started and AEB stop, then either steer to avoid or brake to stop manually
- Repeat several times until trainee is beginning evasive maneuver after the system was reacting to the target and the trainee feels comfortable with maneuver (at least 3)
- Over the next 10 runs, randomly turn the system on/off without the trainee knowing whether the system will react or not. SV driven at 25 mph towards rear of target.

Scenario #2: System Response/No Response – Static Pedestrian Target

- Perform the same scenario as #1 but with a static pedestrian target instead of a static car target.

Scenario #3: System Response Insufficient – Static Car Target

- Set up strikeable static car target in center of lane of travel.
- Enable Subject Vehicle's collision avoidance system (either vehicle's stock CMBS or installed control system)
- Manually drive SV in center of lane at 25 mph toward rear of target
- Allow SV's system to perform AEB stop in response to target
- Repeat several times until trainee is comfortable with maneuver (at least 3)

  - If using stock CMBS, cycle vehicle's ignition in between runs to avoid tripping a system error from performing too many AEB stops consecutively
- Turn off the vehicle's stock CMBS and switch to the separate control system
- Set up the system such that it will start braking in response to the target but not sufficiently to avoid a collision
- Drive the SV at 25 mph toward the rear of the target
- Have the trainee take over with an evasive maneuver (either steer away or brake to stop)
- Repeat until the trainee is comfortable with the maneuver and is taking over late enough to be a close interaction but not a dangerous situation.

Scenario #4: System Response Insufficient – Static Pedestrian Target
- Perform the same scenario as #3 but with a static pedestrian target instead of a static car target

Lateral Control Takeover

Scenario #1: System Response/No Response – Curve Following
- Enable Subject Vehicle's lane centering/path following system (either vehicle's stock LKA or installed control system)
- Drive the vehicle on a straight road at 35 mph approaching a curve.
- Allow the system to follow the curve.
- Repeat a few times until trainee is comfortable with the maneuver
- Switch the system to only lane centering on a straight
- Drive the vehicle on a straight road at 35 mph approaching a curve.
- Trainee takes over as vehicle fails to follow curve
- Repeat a few times until trainee is comfortable with the maneuver
- Over the next 10 runs randomly switch between the system following the curve and not without letting the driver know

Scenario #2: System Fails to Decelerate Sufficiently to Safely Follow Curve
- Enable Subject Vehicle's lane centering/path following system (either vehicle's stock LKA or installed control system)
- Drive the vehicle on a straight road at a high speed approaching a curve.
- The system attempts to follow the curve but does not slow down
- The driver should take over as the system fails to maintain control on the curve

Scenario #3: System Improperly Drifts out of Lane of Travel – Straight Road
- Enable Subject Vehicle's lane centering/path following system (either vehicle's stock LKA or installed control system)
- Drive the vehicle on a straight road at 35 to 50 mph
- The system begins to slowly drift toward the passenger side lane line
- The trainee should take over as the vehicle begins to cross the line
- Repeat this a few times for passenger side as well as for the driver side line

Scenario #4: System Improperly Drifts out of Lane of Travel – Curved Road

- Perform the same scenario as #3 but on a curved road instead of on a straight road. Speed can be varied so lateral accelerations are within safe bounds.

After (i.e., Separate) Driver Training:

- Required Time behind prototype system in vehicle on track before on road
- Annual refresher/touch base aimed at evaluating driver focus during driving task

References

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https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf

https://www.researchgate.net/profile/Guy-Walker/publication/23144717_Does_advanced_driver_training_improve_situation_awareness/links/59e9afffa6fdccfe7f05fe9e/Does-advanced-driver-training-improve-situation-awareness.pdf

http://go.sae.org/rs/525-RCG-129/images/AVSC00001201911.pdf?mkt_tok=NTI1LVJDRy0xMjkAAAF_EuR5PN-wx0TL4xs15GK2LIQ1jVzq-0mleLuQWjvFbJpFexJY0tPIvMolyaqQEYWzppcBgHf-vkhqUhl6z0YRpo7GCQYbfcCcgEGOP0m8Xp21Pg

https://safed.vtti.vt.edu/wp-content/uploads/2020/07/01-004_FinalResearchReport_Final.pdf

Other offerings

https://catdrivertraining.co.uk/motor-industry/autonomous-safety-driver-training/

https://searspointracing.com/programs-experiences/autonomous-vehicle-operator-training/ - learn_more

Appendix A: Level 2 Driver Training Requirements

To receive a Level 2 completion certificate, a student must qualify in all Level 2 events. All of these events are timed events. To qualify, a student must meet two criteria.

1. The student must meet or beat a bogey time, a required number of consecutive times. This bogey time can be a window including lower and upper limits of time in the event.
2. The student must meet a time consistency window.
3. For example, in the Cornering Event a student must demonstrate 5 consecutive laps less than or equal to 22.00 seconds, during which all 5 of those laps must be within 0.30 seconds of each other.

- Be aware that qualifying times within an event can change due to weather or surface conditions. Within the same class, one student may need to qualify in an event at a different pace than other students due to changing surface conditions.
- Within time limitations, every effort will be made to ensure that all participants receive sufficient driving time.
- Four of the five Level 2 events occur in the same location, although not necessarily concurrently, due to facility availability.
- From the moment a student gets behind the wheel of a car, he or she is practicing and at the same time working toward getting the car to pace and qualifying levels in that event.
- Since this is a 2-day class, time is limited in each event. Each event's qualification time period is limited also. Instructors will try to ensure everyone has a reasonable amount of time for qualification in each event. This is all subject to the rate at which students progress through the events.

Classroom Event Discussions

Prior to each event a short classroom session will be conducted to familiarize students with:

- Event basics
- Event learning/demonstration expectations
- Safety requirements/concerns

Level 2 Events

1. Skidcar Oversteer Control Event
2. Constant Radius Event
3. Cornering Event
4. Dynamic Handling Course or VDA Handling Course (road course) Event
5. Slalom Event
6. Rear Wheel Drive Familiarization

- Level 2 is a mid-level driving course; most driving events will be at 85-90% of the vehicles limit.
- Events 1 and 2 from the list above may occur simultaneously. The Skidcar Oversteer Control Event can occur with an instructor along with multiple students in the vehicle. No helmet is needed. Once students are in the vehicle, the instructor will inform students of qualification requirements along with qualification tips.

- In the Constant Radius Event it will be 1:1 student/instructor ratio. Once the student is in the vehicle, the instructor will inform the student of qualification requirements along with qualification tips. Helmet is required.
- Events 3-5 will occur with a 1:1 student/instructor ratio. Helmets will be required for these events. Along with a classroom pre-event session, there will be an in-car tour for the event which re-emphasizes requirements and qualification tips and advice.
- Event 6 is for familiarization (not a timed event) with RWD vehicle(s), with students driving a course to experience differences between FWD and RWD vehicles. Helmets are required.

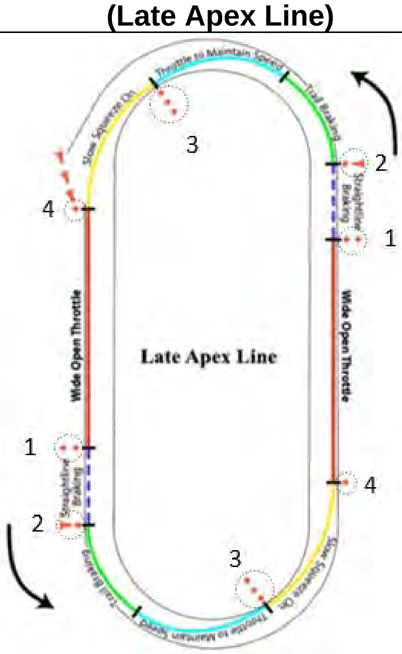
Evaluation

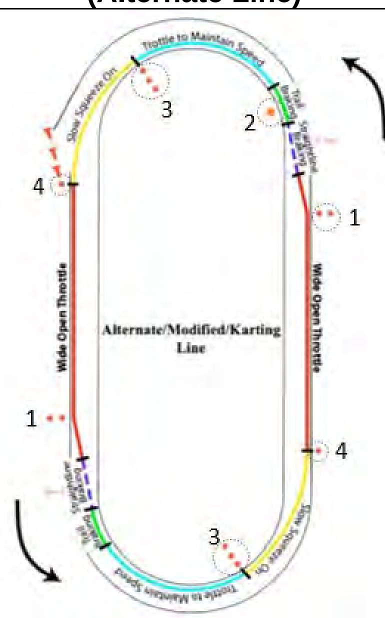
Students will be evaluated in each event objectively, as described in the Class Completion Requirements section, and subjectively.

- Was the student able to grasp the concept of the event and then perform/demonstrate effectively to an instructor?
- Was the student actively engaged in the class completing all events?
- Did the student follow all instructions of safety for each event?

It is possible for a student to receive an “Incomplete” for the class for failing any of these criteria. Instructors will fill out evaluations. PDF files of the evaluations will be sent to the client representative who scheduled the training. All students will receive a certificate in the form of a PDF file. Each student will receive either a “Completed Course” certificate, if all required criteria was met, or a “Participated In Course” certificate, if any of the required criteria was not met.

Some Events to Consider

<table>
<tr><th>¼ Mile Cornering Event
(Late Apex Line)</th><th>¼ Mile Cornering Event
(Alternate Line)</th></tr>
<tr><td>


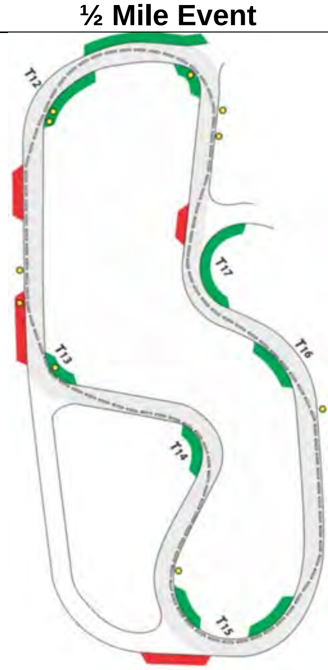
- Level 2 event which is closest to limit of the car.
- There is no loss of control rule in this event.
- There are four sets of cones in each turn that will be helpful. See the circle above, in order they are; 1. brake, 2. turn, 3. late apex, 4. exit.
- Threshold braking technique is important in this event.
- Listen closely. Tire noise will provide helpful feedback.
</td><td>


- Notice how the driving line has changed from the late apex line. There are still 4 groups of cones that are important.
- There are four sets of cones in each turn that will be helpful. See the circle above, in order they are; 1. Turn, 2. Point the car to here, 3. late apex, 4. exit. Notice their locations above and how it has changed from the late apex line.
</td></tr>
</table>

- The orange cones usually indicate which side of the course the student should be driving on.
- **CONE 1.** There is no slowing down before the brake cones in this event.
- Brake at the 1st cone. Modulate the brake as needed.
- **CONE 2.** Stay close to the right white line until the "turn cone."
- Three things happen at the same time at the turn cone. 1. Turn, 2. Look to the apex cones, 3. Trail brake.
- Trail braking is slow and continuous reduction in the brake pedal pressure.
- Do not add brake pressure while turning, which can result in oversteer/spins.
- Maintain tire squeal by modulating throttle.
- **CONE 3.** Slowly squeeze throttle on and driving the car towards Cone 4.
- **CONE 4.** The driver should be at or close to full throttle.
- **REMEMBER**: Start slow and increase pace as comfort level builds. Establish a rhythm.

- Unlike the late apex line there is no turn cone in this line.
- The alternate line requires a turn-in at the brake cones.
- Point the car in towards the cone 2 in the diagram above.
- Keep wide open throttle until the brake point.
- There is no reference point for the brake point. The driver has to do it by "*feel*".
- At the brake point, the driver will need more brake pressure because of a shorter braking zone.
- Keep the car close to the inside.
- Trail braking will be for a shorter distance/period than the late apex line.
- Modulate throttle pressure to maintain a constant, consistent tire squeal.
- The downhill side of the course will be slightly off-camber. Each turn will need slightly different brake pressure.
- Listen closely. Tire noise will provide helpful feedback.
- This is the required driving line for qualification in Level 2.
- To qualify in this event the participant must have 5 consecutive laps below a time set by the instructors. This qualifying time is dependent on weather and surface conditions. All 5 laps must be within .30 seconds of each other.
- **REMEMBER**: Start slow and increase pace as comfort level builds. Establish a rhythm.

Dynamic Handling Course
½ Mile Event

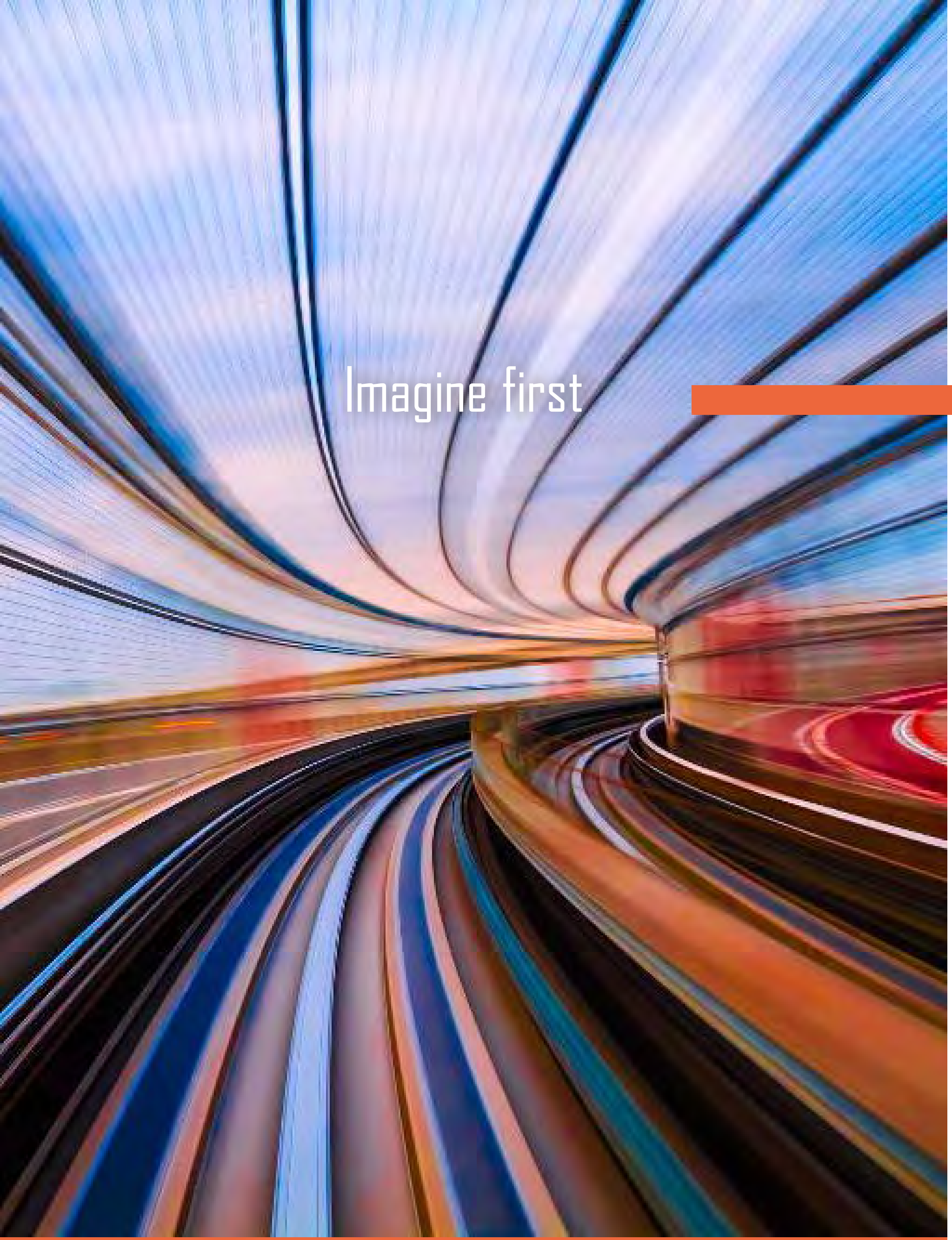


- Instructors will help students fine tune the driving line.
- A window for qualify times will be established by the instructors. These times are dependent on weather and track conditions. 5 consecutive laps within this window must be run, with all times within 1 second of each other.
- There is a loss of control rule for this event. If a participant spins the car or put 4 tires in the grass, then the student will receive an "Incomplete" for the class.

Slalom Event

- Cones are 100' apart.
- Notice the driving line is a modified sine wave.
- Entrance speed to qualify in this event typically will be 50-55 mph.
- Look at where the car should pass by each cone.
- Start turning well before each cone.
- Don't let the amplitude of the wave get too large.
- Slowly, consistently adding throttle increases stability of the car against oversteer.

• The in-car instructor will determine, in each case, whether an “episode” constitutes a loss of control. • Notice the yellow dots indicating cones on the course for braking, turning and apexes. • **REMEMBER**: Start slow and increase pace as comfort level builds.	• It is generally good to be much more assertive with the throttle around cone 6. • Making smooth steering inputs keeps the car more stable. • Don’t make lazy, slow steering wheel inputs to be smooth. • Performance driving turns are smooth and quick, but not abrupt. • Steering wheel input should be around 90º. • Remembering all of this is hard. Relax and enjoy the experience. • A student is permitted 2 losses of control (spin). On the third loss of control, the student will receive an “Incomplete” for the class. The in-car instructor will determine, in each case whether an “episode” constitutes a loss of control. • To qualify in this event the participant must have 5 consecutive passes below a time set by the instructor. This qualifying time is dependent on weather and surface conditions. • **REMEMBER**: Start slow and increase pace as comfort level builds.



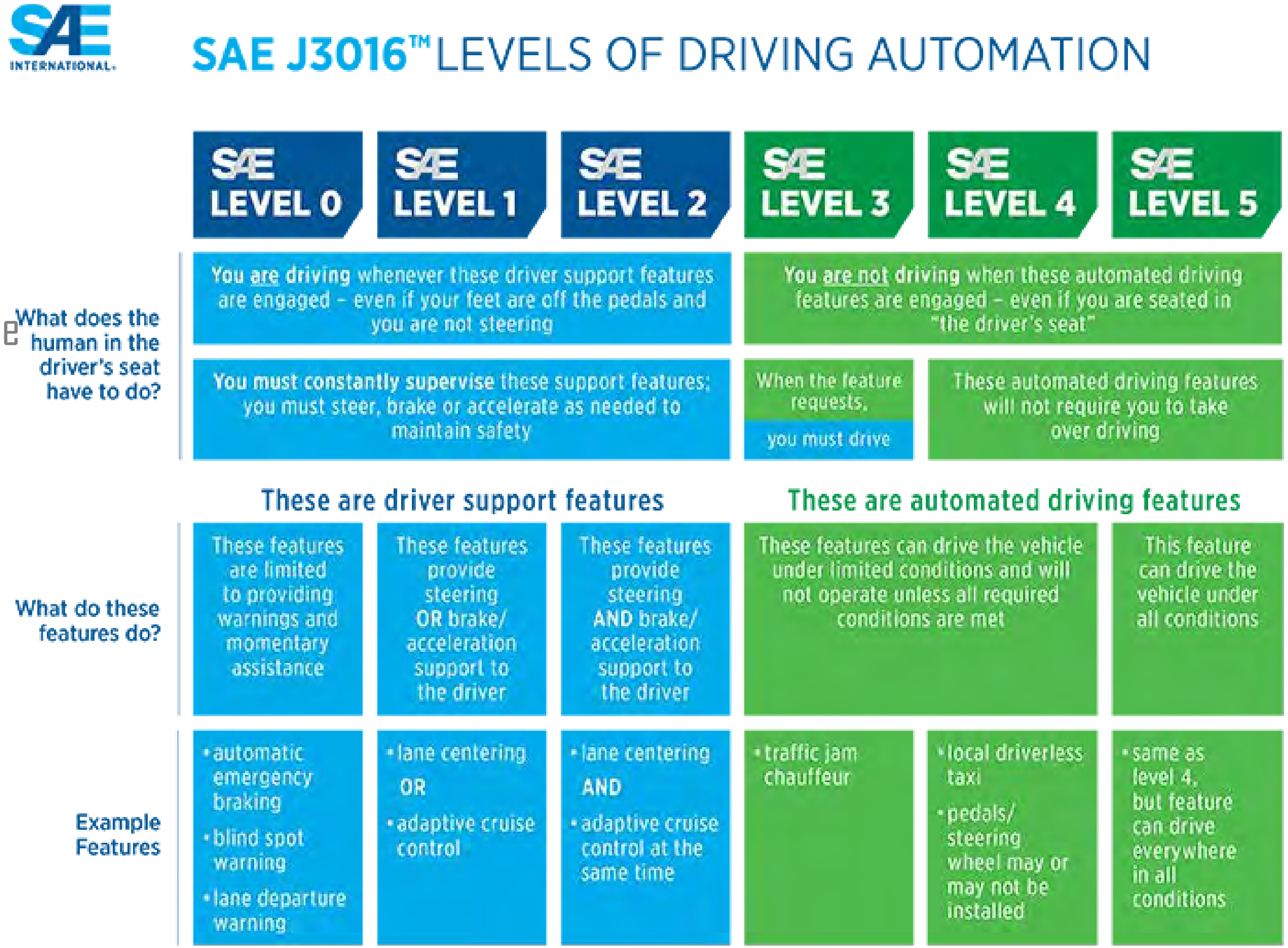
Automated Driving System -
- Driver Training

What is an ADS?

- Defined by SAE using their number scale

0-2 Driver is fully responsible

3-5 The vehicle can take responisbility



TRC next

What is an ADS?

- Defined by SAE using their number scale

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

Full Automation

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

TRC next

What should our expectations be?

- ADS equipped vehicles are not at the production level, they are all prototypes, without full validation
- Therefore, expect that they could respond inappropriately to their surroundings or abruptly have inappropriate maneuvers
- Monitor your driving environment, know when vehicles are to your side and understand traffic ahead

TRCnext

Components of an ADS (Sensors)

- Lidar
  - Provides a point cloud of surrounding environment
  - Strength: Works well at night, precise
  - Weakness: Affected by weather, low resolution, high compute load
- GNSS/IMU (GPS)
  - Provides location and movement data
  - Strength: Can provide very precision, low compute localization with RTK
  - Weakness: Low precision without RTK, requires line of sight with sky
- Radar
  - Provides object tracking with both distance and speed
  - Strength: Good in adverse weather
  - Weakness: Noisy, which can lead to false detections, not great at distinguishing objects
- Camera
  - Provides high resolution image that can be used for identification and range estimates
  - Strength: Versatile and effective object detection
  - Weakness: Requires good lighting, affected by weather
- Ultrasonic
  - Provides object distance for short range (up to 16ft)

TRCnext

Components of an ADS (Other)

- Computer
  - Serves as the "brains" of the ADS. Interprets and fuses sensor data as well as serving as a data recorder
  - Monitor can be used to see path planning algorithm (should not be used by safety driver)
- Safety Driver
  - Monitors the environment and behavior of vehicle
  - Decides when to engage/disengage vehicle
  - Drives vehicle when ADS is not engaged
- Disengage/Emergency Stop Button
  - Provides a hard and fast method of ensuring vehicle disengages from automation
- Other ways of disengaging automation include
  - Moving steering wheel
  - Applying brake or throttle
  - Turn off vehicle power

TRCnext

Fundamentals of Automation

- Localization
  - Most ADS vehicles use a comprehensive map with detailed locations of lane lines, intersections, etc.
  - To make proper use of this information the vehicle must determine its location/orientation within the map
  - GNSS/IMU provide the easiest method for this but fall short based on the limitations of GNSS
  - Lidar can be used with a prerecorded point cloud to match up but also have limitations
  - Other options rely on vision based systems to determine lane lines and avoid requiring the same level of localization
- Path planning
  - The vehicle requires to know up front where it is going, and then creates a route connecting its current location with the final
  - This level is similar to current routing done via say google maps, but taking into account individual lanes
  - In addition, the vehicle may recalculate this at a given frequency to account for slow traffic, passing, and obstacles
- Detection
  - While the vehicle is navigating the path, it should constantly monitor for any obstacles, pedestrians, vehicles, signs, and other relevant information

These are all dependent on the specific vehicle *and* automation software being used and vary significantly

TRCnext

Expectations when Driving with Automation Enabled

- Stay engaged in the driving task
  - This will require more focus than normal driving, because the vehicles actions could be unpredictable, so you need to keep alert for **both** surrounding environment and your vehicle itself
  - As such make sure that you assess for yourself that you are able to focus adequately
    - Take brakes as needed
- ChAT Method
  - Check – first, check yourself, check for hazards, check all mirrors and check your blind spot
  - Assess – next, assess your position, assess the road, assess the situation and assess the next step
  - Take Over - then, focus on taking over the operational controls of the vehicle
  - Chat conveys a two way conversation where you are both responsible for acting
- When should a takeover occur?
  - Anytime you feel that an unsafe situation is occurring, you feel the system is not performing well
  - Based on monitoring environment and assessing the appropriate path: other drivers, roadway, weather, or visibility
  - Examples: Vehicle doesn't detect pedestrian or vehicle ahead (could be about to cross path), steering jerks to the right, vehicle brakes abruptly, or vehicle enters new environment outside of operation conditions (starts to rain or on ramp), or the vehicle is about to brake a traffic law

TRCnext

On Track vs On Road

- On Track
  - Understand what the other actors in the test are and which ones are strikeable. Vehicles can and should be allowed to fail if it involves the strikeable targets.
  - Goal is to collect data in specific cases conducted repeatedly to prove out safety and initial safety
- On Road
  - There are no strikeable targets, the surroundings can change quickly, nothing is scripted, and objects/people can sometime appear out of no where
  - Be alert and ready to take control
  - Look for traffic patterns and be aware of speed limit and other possible rule violations
  - Look for changes to the normal operation of a roadway that may impact a vehicle's ability to respond correctly (e.g. Work zone)

Law Enforcement and Policy

- Automated driving is still new and government policy is still catching up especially at different levels
  - In Ohio, registration is currently required to conduct testing on public roads
    - Register with DRIVEOhio
    - Assure that the vehicle is safe and actively monitor it at all times when automation is engaged
    - Designate an operator responsible for driving the vehicle and ensure it is following all traffic regulations
    - Cooperate fully with law enforcement
    - Report any collision originating from the operation of the autonomous vehicle while engaged
  - In some cases this testing allows for standard rules to not apply (i.e. platooning)
    - If a law enforcement officer does pull you over, explain the testing and that approval was given. It is possible that you may be given a ticket and this can be resolved in the courts

TRCnext

Let's Discuss

What would you do in ___ situation?

Questions about ADS capability

Questions about ADS functionality

Other Questions

Appendix F

EASE Platoon Driver Sign-Off Checklist

Driver Training Sign-Off Sheet

	Bart Cooper	Justin Montgomery	Mike Vannatta	Dan Gregory
Classroom Content Presentation				
Platooning Background				
ADS Basics				
Safety				
Operational conditions				
On-Track vs. On-Road				
Law Enforcement				
Example Videos				
Pre-Trip Checklist				
Conditions of Use				
Vehicle Equipment Training				
Main System overiew				
Main Power Cabin				
Component Locations				
SPOD				
HMI				
Platoon Lights				
Power Indicators				
Pre-trip Comms				
Headset EARTEC				
Driver Training Lead Truck				
Engaging Platoon **x30**				
Disengaging Platooning **x30**				
ACC engaged in Platooning **x20**				
Disengage w/ Brake **x20**				
Disengage w/ Accelerator **x20**				
Disengage w/ HMI **x20**				
Cut-in **x5**				
Cut-in w/brake **x5**				
Driver Training Follow Truck				
Engaging Platoon **x40**				
Disengaging Platooning **x30**				
Continous Platooning 6hr.				
ACC explanation				
+20 Approach Engage				
Disengage w/ Brake **x20**				
Disengage w/ Accelerator **x20**				
Disengage w/ HMI **x20**				
Cut-in **x5**				
Cut-in w/brake **x5**				
Rapid hard brake engagement				

By signing this document, all parties agree that the mentioned training scenarios and information have been performed and discussed in detail within satifactory performance measures and feel comfortable operating the system outside of TRC Inc.

Trainer Signature: ______________________________ **Date:** ________________

Project Manager Signature: ______________________________ **Date:** ________________

Trainee Signature: ______________________________ **Date:** ________________

Appendix B
Passenger Vehicle Supporting Documents

Appendix B1
Passenger Vehicle Safety Management Plan

DRAFT SAFETY MANAGEMENT PLAN

VERSION 3 (PASSENGER VEHICLE DEPLOYMENT)

Ohio Rural Automated Driving Systems (ADS) Project

Prepared for:

Prepared for: DriveOhio

Prepared by: CDM Smith with TRC and OU

December 6, 2023

CDM Smith

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Acronyms and Abbreviations

ADS	Automated Driving System
ADS Project	Ohio Rural Automated Driving System Project
AEB	Automatic Emergency Braking
AS	AutonomouStuff
ASIL	Automotive Safety Integrity Level
AV	Automated Vehicle
AVPP	Autonomous Vehicle Pilot Program
CAM	Corrective Action Management
CASC	TRC Corporate Administrative Safety Committee
CE	Controlled Environment
ConOps	Concept of Operations
C-V2X	Cellular Vehicle to Everything
DBW	Drive-by-Wire
DMP	Data Management Plan
DPP	Data Privacy Plan
DSRC	Dedicated Short Range Communications
E/E	Electric and Electronic
EMS	Emergency Medical Services
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOG	Facility Operating Guidelines
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HD	High-Definition
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transportation Systems
L2	Level 2 Automation
L3	Level 3 Automation
LiDAR	Light Detection and Ranging
NHTSA	National Highway Traffic Safety Administration

OBU	On-Board Unit
ODD	Operational Design Domain
ODOT	Ohio Department of Transportation
OEM	Original Equipment Manufacturer
OU	Ohio University
PII	Personally Identifiable Information
QM	Quality Management
R&D	Research and Development
ROI	Region of Interest
RSU	Roadside Unit
RTK	Real-time Kinematic
SAE	SAE International, formerly Society of Automotive Engineers
SGO	Standing General Order
SMP	Safety Management Plan
SOP	Safety Operational Plan
SPaT	Signal Phase and Timing
TRC	Transportation Research Center
UC	University of Cincinnati
UCLA	University of California- Los Angeles
USDOT	United States Department of Transportation
VRU	Vulnerable Road Users

Section 1

Introduction

1.1 Project Overview

The U.S. Department of Transportation (USDOT) awarded an Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of the Ohio Department of Transportation (ODOT), JobsOhio, Transportation Research Center (TRC), Bosch, Ohio University (OU), University of Cincinnati (UC), University of California- Los Angeles (UCLA) and Southeast Ohio community partners. The Ohio Rural Automated Driving Systems Project (ADS Project) will pilot how automated vehicles could improve safety for drivers, passengers, and other travelers in rural settings. The ADS Project has two vehicle sets (light-duty and heavy-duty). This document covers light-duty vehicles.

The intent of the project is to test automated passenger vehicles on public roads in the Athens, Ohio area with features that emulate Level 3 (L3) automation per the SAE International levels of automation. The scope of the deployment is to demonstrate automated driving on rural public roads of varying functional classification during different times of the year to understand how the vehicles perform in multiple real-world situations. The deployment is designed to evaluate several use cases: single vehicle automated driving, cooperative lane change, and cooperative lane merge.

Since the goal is data collection, the vehicles will carry no passengers outside of the project team operators and field support on public roads. However, the data collected will be critical to project goals, as well as researchers involved in vehicle automation and the project team measuring project performance.

1.2 Safety Management Plan

The Safety Management Plan (SMP) is a companion document to the systems engineering documentation, including the Concept of Operations (ConOps), System Requirements, Interface Control Document (ICD), Data Management Plan (DMP), Data Privacy Plan (DPP), Human Use Approval Summary, and the Project Evaluation and Performance Measurement Plans. The purpose of the SMP is to identify the safety risks associated with the project's passenger vehicle automation deployment and lay out a plan to promote the safety of the participants and surrounding road users including drivers, pedestrians, and bicyclists. The plan describes the potential safety risk scenarios related to the deployment, assesses the level of risk for each safety scenario using a Risk Assessment Matrix that is loosely based on the Automotive Safety Integrity Level (ASIL) process defined by the International Organization for Standardization (ISO) 26262, provides mitigation strategies, and references Safety Operational Plans (SOP) by Ohio University (OU) and the Transportation Research Center (TRC) for deployment on public roads. OU and TRC are responsible for updating their SOPs per the needs of the project and following their SOPs requirements.

The SMP is developed in coordination with the proposed operational practices described in these conceptual documents for each deployment. The SMP provides and documents the guidance on designing a safety-critical system that can eliminate hazards from the design, reducing risks by modifying the design to lower the probability of the occurrence of the hazard, or at minimum, mitigating the impact of the hazard if it does occur. The System Requirements include functional requirements, interface requirements, data requirements, performance requirements, security requirements, etc., for all systems that will be deployed as part of the ADS Project. The SMP and referenced documents in this SMP lists all the requirements and the safety risks associated with those requirements. The Interface Control and System Requirements documents should refer to the SMP to make sure all safety risks listed in this plan are addressed while designing and testing the system.

The SMP describes the underlying needs of the deployments to validate the overall safety and understand the impacts of various scenarios such as power outage, communication failures, unintended or malicious attacks, severe crashes, and adverse weather conditions. The approach to developing the risks was to collaboratively identify and document them with the project team at TRC and OU, have the team assign the risk scores, and collaboratively identify and document the mitigations to minimize the risks.

1.3 Operating Scenarios

This SMP evaluates the risks and identifies mitigations based on an L3 automation scenario. There is the possibility that some tests and data collection runs are completed without the autonomy stack engaged in the vehicle operation. The potential scenarios are as follows:

- **Sensor Mode** – The vehicle sensors (radar, light detection and ranging [LiDAR], etc.) are on and recording raw data as the vehicle is driven manually. The ADS stack is not engaged to calculate real-time decisions related to the operation or trajectory of the vehicle.
- **Shadow Mode** – The ADS stack is running in the background, but the vehicle is being driven manually. When Apollo is not engaged, it only runs object detection and does not generate any control information. Raw sensor data is also being recorded.

  The team is developing a data collection method, named Shadow Mode, to use while a human driver is driving the vehicle to ensure safety. Shadow Mode will have the ADS software stack running in the background. This will permit the team and future researchers to evaluate what the ADS software stack would have done in certain situations when ADS operation may have been unsafe.
- **Automation Mode** – The ADS stack is fully engaged and is operating the vehicle based on the decisions made by the software. While the ADS controls the vehicle, a human operator monitors the operation of the vehicle and may take control based on the situation or how the ADS is reacting. Raw sensor and control data are also being recorded.

1.4 Document Overview

This document includes the following chapters, which detail the project's passenger vehicle safety-critical system that is designed to address operational risks for deployment:

- Section 1 – Introduction describes the project overview to the SMP.
- Section 2 – Safety Risk Process and Approach describes the overall safety risk process and approach to safety risk management.
- Section 3 – Safety Analysis and Risk Assessment Plan identifies the safety risks and provides an analysis and assessment of the safety scenarios identified within the passenger vehicle deployment.
- Section 4 – Safety Operational Plan describes the safety operational concept including functional requirements and system-wide fail-safe mode.
- Section 5 – Coordination with Other Tasks describes how this SMP coordinates with related project deliverables.
- Section 6 – Summary/Conclusions summarizes this document's conclusions.

1.5 References

Table 1-1 lists the documents and literature used to gather information.

Table 1-1. References

Doc. No.	Title	Rev.	Pub. Date
1	Ohio Manual of Uniform Traffic Control Devices. Ohio Department of Transportation https://www.dot.state.oh.us/raodway/omutcd/Pages/default.aspx	–	Jan. 13, 2012
2	Preparing a Safety Management Plan for Connected Vehicle Deployments. U.S. Department of Transportation https://www.its.dot.gov/pilots/pdf/CVP-Tech-Assistance-Webinar-Safety-Management_Final.pdf	–	Dec. 7, 2015
3	Connected Vehicle Pilot Deployment Program Phase 1, Safety Management Plan. ICF/Wyoming https://rosap.ntl.bts.gov/view/dot/30734	–	March 14, 2016
4	Connected Vehicle Pilot Deployment Program Phase 1, Safety Management Plan. Tampa (THEA) https://rosap.ntl.bts.gov/view/dot/30733	–	April 6, 2016
5	NYC CV Pilot Deployment: Safety Management Plan – New York City. https://rosap.ntl.bts.gov/view/dot/31726	–	April 22, 2016
6	USDOT Guidance Summary for Connected Vehicle Deployments: Safety Management. https://rosap.ntl.bts.gov/view/dot/31556	–	July 1, 2016
7	ISO 26262, Road Vehicle Functional Safety Standards. https://www.iso.org/standard/68383.html		Dec 2018

1.6 Project Vehicles

The Ohio Rural ADS Project has specific vehicles using Autoware or Apollo platform software operating at SAE L3 on public roads in the Marysville and Athens, Ohio areas (as detailed in the ADS Demonstration Site Map and Installation Schedule report). Also, the project has two different teams operating the vehicles (TRC and OU). The project vehicles include:

- 2017 Ford Fusion: VIN number 3FBAX9CG3MXA86213 (TRC owned and operated)
- 2021 Ford Transit 350: VIN number 1FBAX9CG3MXA86213 (ODOT owned and TRC operated)
- 2021 Ford Transit 350: VIN number 1FBAX9CG5MKA84568 (ODOT owned and TRC operated)
- 2021 Chrysler Pacifica: VIN number 2C4RC1S7XMR572459 (OU owned and operated)

Section 2

Safety Risk Process and Approach

This section describes the safety risk process and approach for the project's passenger vehicle deployment and the procedures that the project team will use to manage risks.

The project team has defined the SMP process that will be followed to assure that the development, testing, and deployment process is clearly outlined (Figure 2-1). This process would enable multiple checkpoints to evaluate safety risks and to review that the risks were tested (in the Controlled Environment Test Plan and Field Deployment tests) and mitigated (this SMP). With an eye toward protecting the project team operators and other highway users and pedestrians, this comprehensive process allowed the team to exhaustively review risks to personal injury due to the public road deployment. One of the goals of the SMP is determine the limitation of use for the Autoware and Apollo automation software platforms for use on public roads in the project vehicles. The CE testing results, and the trained drivers' feedback, are inputs to software limitation of use on public roads. The workflow chart (Figure 2-1) provides how and what is included in generating the inputs and data for the SMP.

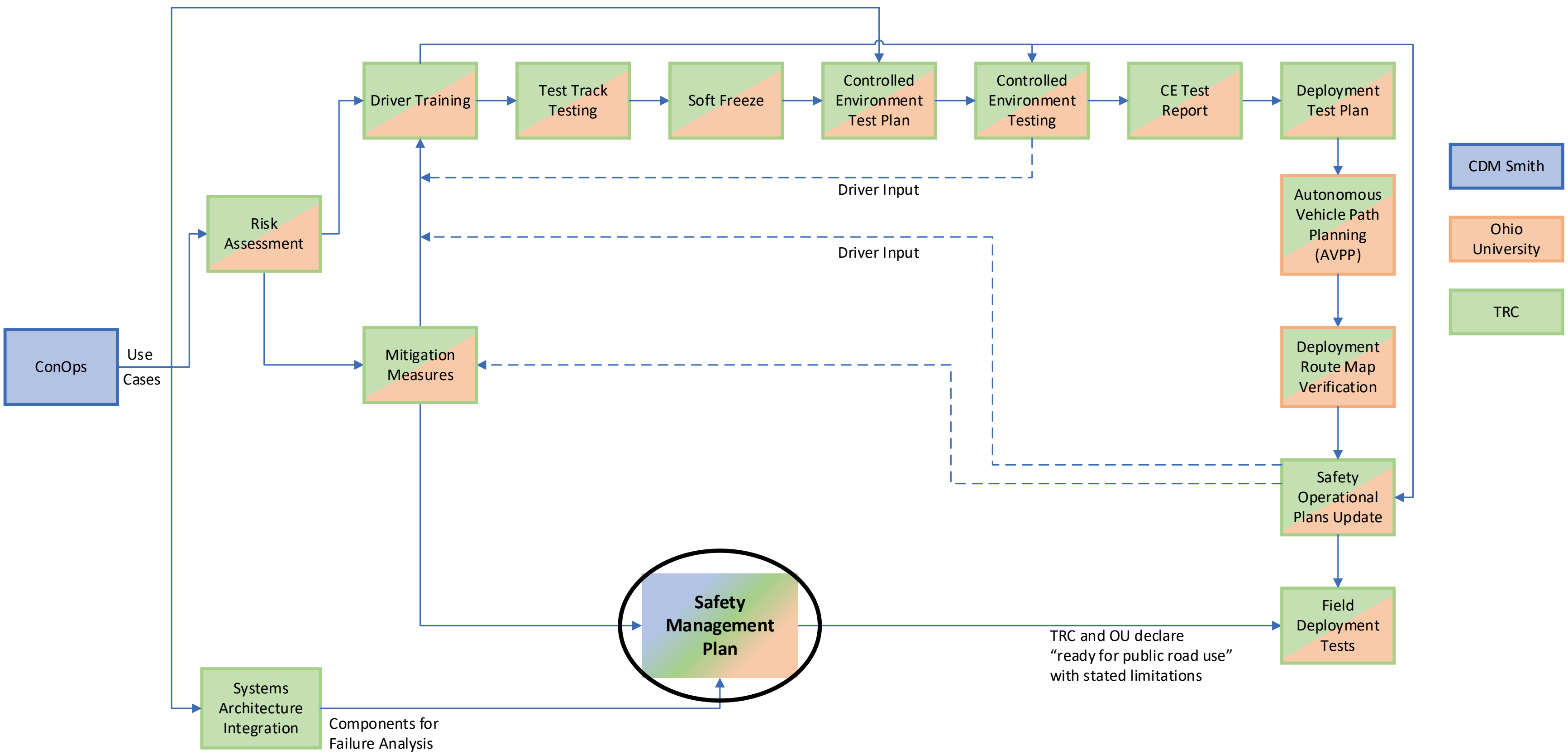

Figure 2-1. Safety Management Plan Process Flowchart

The SMP consists of identifying the safety risks, performing a Hazard and Risk Assessment, developing mitigation measures, and creating a safety operational concept plan based on the identified safety requirements (Fail-Safe System Mode, Quality Training, etc.). As shown in Figure 2-1, the SMP process starts with the ConOps and the use cases that were developed. These feed the Systems Architecture, the Controlled Environment Test Plan, and the Risk Assessment that is documented in Section 3. The Risk Assessment helps inform the Driver Training Plan so that those responsible for the operation of the vehicles know the associated vehicle capabilities and serves as the basis for the Mitigation Measures that result from the Risk Assessment. The project and deployment teams will both have checks in place to assure that the mitigations are implemented to reduce risk. The vehicles are subject to testing at the TRC Test Track. This testing determines the soft freeze of the software platform which is the start of the controlled environment (CE) phase. The CE Test Plan is developed, which guides the CE testing. The CE tests are conducted which results in a CE Test Report. The CE testing output can be used to update the Driver Training Plan through driver input before finalizing the Deployment Test Plan. The State of Ohio's Autonomous Vehicle Pilot Program (AVPP) registration is required for all automated vehicle deployers (L3 and higher) in Ohio and details the vehicles and routes. If additional mitigations are identified, these will be fed back into SMP updates. Field tests consist of public road deployment routes in the Marysville and Athens, Ohio areas. Before the public road deployments are conducted, the deployment route maps need to be verified. After the SMP is developed, TRC and OU must modify their SOPs using the SMP and reference documents as input. TRC and OU are responsible for declaring that the automation software (Autoware or Apollo) on the project vehicles has been tested and given the limitation of use (document in this SMP and its referenced documents) that public road deployment can proceed based on their modified SOPs. The CE Test Reports prepared by OU and TRC document this process. These reports are in the project files.

2.1 Automated Vehicle Pilot Program

On May 9, 2018, Ohio Governor John Kasich's executive order authorized autonomous vehicle testing, subject to certain safety requirements, on any Ohio public road or highway for Level 3 automation or higher. TRC and OU will enroll their project test vehicles in the AVPP to operate project vehicles in Ohio for the ADS Project. TRC/OU will register with DriveOhio and provide them with the following information: business name and address; vehicle make, model, and license plate number; contact information for the driver/designated operator; proof of insurance; the municipalities where they plan to test; information on the conditions under which the vehicles can operate in fully autonomous mode; and safety certifications. In addition, TRC/OU will provide assurance that the test vehicles can operate safely by proving that the vehicles can comply with all traffic laws and can safely shut down if it begins malfunctioning. TRC/OU will cooperate fully with law enforcement in the event the vehicle violates any laws or is involved in any collision. The vehicle's operator must also report any collisions to DriveOhio, per the incident reporting section of the SMP. Lastly, TRC/OU received approved AVPP forms before operating on Ohio public roads. This AVPP form only applies to Ohio public roads.

Steps to follow for the AVPP request submission:

1. Current form submission site: https://ohiodotprod.service-now.com/do

2. Drive Ohio will provide a link to the new process. The following information will be required:
    a. License plate (State of Ohio)
    b. Make/Model of vehicle:
    c. Driver address information
    d. Address information
3. Self-insured status
4. Operational Design Domain (ODD) – Process for maintaining a safe operating environment:
    a. Always have safety driver with sole responsibility to monitor the road, vehicle, and be ready to take immediate control or corrective action of the vehicle.
    b. The safety driver is not permitted to operate the automation system or monitor any data feeds but must know the route being undertaken by the system.
    c. The automation operator will control the automation system and inform the safety driver of engagement and disengagements along with anything indicated by the data feeds that is incorrect such that the safety driver can take immediate control of the vehicle.
    d. The automated vehicle will always remain at or under posted speed limits, use indicators for turns, and obey all traffic laws.
    e. The safety driver will engage the hazard flashing lights of the vehicle after a manual disengagement occurs and if there are other vehicles that may have to take action around our vehicle.
    f. Include SOP, CE test plan, and driver training plan for more information about our processes.
5. Limitations
    a. Can only operate in mapped areas
    b. Speed will be 55 mph or less
    c. Operating conditions such as precipitation or temperature
    d. Operating guidelines-hours
    e. Operating guidelines for traffic conditions
6. Identify safety scenarios at system level as defined in the ConOps.
7. Assess the level of risk for each safety scenario.
8. Develop a safety operational concept for each scenario if it is identified as high/medium risk.

2.2 Risk Process and Approach

To protect the safety of project team operators and other highway users (i.e., pedestrians, bicyclists, and other motorists), a process inspired by the ISO 26262 is used for testing, deployment, and closeout stages. Figure 2-2 illustrates the development of the SMP, which follows the process defined in the USDOT guidelines.

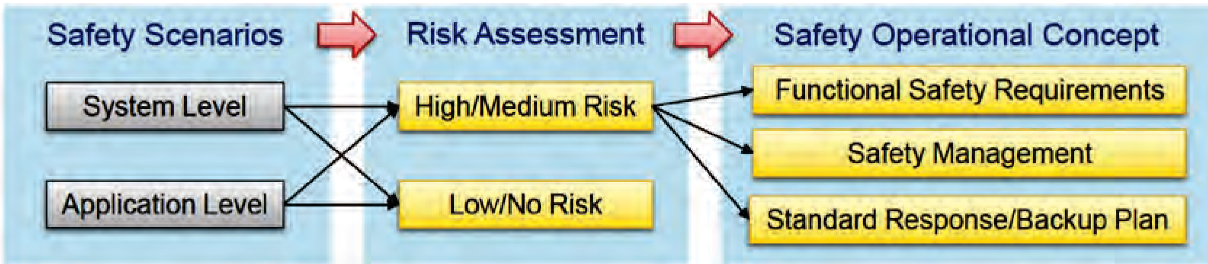

Figure 2-2. Safety Management Plan Development Process
(Source: USDOT Guidance Summary on Safety Management Plan)

It is anticipated that through each phase of the project, there is potential for additional risks to be identified. When that is the case, the project team will identify the risk and determine what, if any, mitigations are required to continue to assure the safety of the surrounding individuals. These risks and mitigations will be documented in the SMP and TRC/OU must modify their SOPs, as needed.

2.3 Safety Stakeholders

There are many stakeholders that are responsible for the development, testing, and deployment of the project, as well as stakeholders that are responsible for maintaining and operating the roadway network. It is the project team's responsibility to assess the potential hazards and mitigation strategies with stakeholders once complete, so they are aware of the potential risks and the mitigations put into place.

The following are safety response stakeholders for the passenger vehicle deployment:

- USDOT (including Federal Motor Carrier Safety Administration [FMCSA])
- ODOT – Traffic Safety, Construction, Maintenance, Geographic Information System (GIS)/Intelligent Transportation System (ITS), Information Technology (IT), Telecom Programs (including equipped snowplows), DriveOhio
- Ohio State Highway Patrol
- Ohio Department of Public Safety
- Municipal Managers
- Local Police, Fire, and Emergency Medical Services (EMS)
- Transportation Research Center, Inc.
- University of Cincinnati
- University of California Los Angeles

- Ohio University
- AutonomouStuff (AS)
- Mandli

2.4 Law Enforcement/Emergency Responder Coordination

State and local agencies have their own emergency response plans for various events, such as severe incidents, natural disasters, or planned events. The project team will coordinate with law enforcement and emergency responders on what actions are expected from both the agencies and the deployment program in response to the emergency situations identified in this SMP.

The project team will work with local law enforcement and emergency responders and inform them about the field deployment when it occurs. As with any emergency involving a vehicle or pedestrian, the project team operator should follow their (TRC or OU) SOPs. The project team will conduct a law enforcement stakeholder meeting focused on the Athens area routes and project activities.

2.5 Safety Risk Monitoring

The project team will ensure safety risk controls are effective and new safety risks are identified by considering the following items during a scheduled safety review:

- Verifying that periodic checks on the equipment, software, interfaces, and processes are being conducted.
- Reviewing feedback and information received from the project team operators.
- Reviewing any incident reports
- Keeping up to date with best practices and lessons learned from similar deployments.
- Coordinating with law enforcement, as necessary
- Conducting internal reviews of project documentation

TRC/OU will be monitoring vehicle operating data as well as vehicle performance for safety risks and track them throughout the deployment duration via the safety review process. Details on TRC's and OU's SOPs are summarized in Section 4.

2.6 National Highway Traffic Safety Administration Automation Incident Reporting

This section describes NHTSA's crash reporting requirements for Level 3 ADS-equipped vehicles. This requirement is based on the Standing General Order (SGO) reporting obligations for ADS-equipped vehicles and equipment manufacturers served with SGO. The entities named in the SGO must report a crash if Level 3 ADS-equipped vehicle was in use at any time within 30 seconds of the crash and the crash involved a vulnerable road user or resulted in a fatality, a vehicle tow-away, an air bag deployment, or any individual being transported to a hospital for medical treatment or vulnerable road users (VRU) and this needs to be reported within 1 to 10 days depending upon the crash severity type.

2.7 Ohio Incident Reporting

The State of Ohio Highway Patrol is requesting that all incidents involving law enforcement, regardless of the nature of the law enforcement incident be reported by TRC and OU (for their respective vehicles) using the website below during the duration of the deployment on the public road routes in the Athens area. Appendix A provides a copy of the Incident Report form.

https://ODOT.formstack.com/forms/driveohio_av_reporting

Section 3

Safety Analysis and Risk Assessment Plan

The goal of the Safety Analysis and Risk Assessment Plan is to guide the project team in eliminating hazards from the deployment or to mitigate risk if it does occur.

3.1 Identify Safety Scenarios

This section discusses the safety scenarios at system level for the passenger vehicle deployment. The safety risks identified are generalized failure modes intended to enumerate failure modes specifically related to the operation of the ADS at L3. This list does not cover failure modes related to the original equipment manufacturer (OEM) vehicle platform that the ADS stack has been built on top of. It is assumed that failure modes/mechanisms of the underlying OEM vehicle platform have been appropriately defined and accounted for by the OEM. This list is generalized into system failures that have differing causes but generally the same mitigation strategy.

It should be noted that the failure mechanisms listed here are specifically written with the intent that the ADS stack will be AS's variant of Autoware and Apollo. The Autoware stack is used in the Ford Fusion project vehicle. The Apollo stack is used in the Ford Transit vans and the Chrysler Pacifica project vehicles. The Autoware version that is currently being used is based on the "enu_projector_oap8" fork from github. It is understood that some failure mechanisms will reach across ADS stacks, but differences could arise when evaluating these failure mechanisms across different stacks. A safety review will be performed prior to other ADS stacks being deployed, such as Apollo, or other versions of Autoware to determine if any other mitigations are required.

The failure risks, possible causes, impact, and mitigation strategies enumerated in Table 3-1 are specifically for the Autoware and Apollo platforms. This SMP will be reviewed in the future to update the table based on the software platform used and its capabilities as a basis for the future safety evaluation of the ADS stack during the CE testing and/or deployment. As indicated previously, an additional safety review will take place and this commentary will be used as the basis for that review prior to its deployment on public roads.

Table 3-1. Safety Risk Identification for Autoware and Apollo Platforms

	Failure Mechanisms	Potential Causes	Impact	Apollo Mitigation Strategy	Autoware Mitigation Strategy
1	Global positioning system (GPS) fails to provide location	▪ Power loss to the NovAtel unit ▪ NovAtel hardware failure ▪ NovAtel software failure ▪ Communication failure between Spectra PC and NovAtel ▪ Loss of satellite connection stemming from multiple causes	GPS is currently the only localization method. Without a proper location signal coming from the GPS, the vehicle will not be able to accurately localize itself within the environment that it is operating. As an example, this could cause the vehicle to not operate within a lane, miss traffic control devices, etc.	The Apollo stack includes a heartbeat monitoring system, like what TRC has implemented for Autoware. The status is shown inside DreamView, the Apollo viewer interface, which is indicated by a red or green status indicator. An additional dash light shows if the GNSS has an RTK fix with a blue light. Other software modules within Apollo also offer this same indicator system of red/green status, so each is acting independently. Apollo will not allow the system to engage if GPS data is not available.	TRC has added a software heartbeat signal monitoring software. This checks all primary sensors (GPS, real-time kinematic [RTK], LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This software will not allow the ADS stack to be engaged should certain checks not be met and will lead to disengagements of the ADS stack should sensors timeout. The timeouts have been chosen by TRC to be small but not lead to false positives. It should be noted that while the timeouts are small, it would still be possible for safety critical events to occur in the time frame of the timeout. This system is meant to aid safety and the safety driver but does not eliminate the requirements of the safety driver. This does not monitor the quality of the data, just that the sensor is currently active in the system. For example, this will enable the system to monitor that the camera is currently transmitting data but would not check if there is a camera blockage leading to non-useful pictures being transmitted.
2	RTK correction loss	▪ Power loss to cellular hotspot (e.g., Verizon wireless hotspot) ▪ Cellular hardware failure ▪ RTCM software failure ▪ Cable failure ▪ Loss of cellular connection stemming from multiple causes ▪ NovAtel fusion computation ▪ Insufficient number of satellites ▪ Local disruption of satellite information (e.g., multipath)	RTK corrections are required for the fine localization of a vehicle. GPS will get location accuracy within a few meters, but the RTK corrections are required to refine that signal and get the accuracy down to centimeter level. This level of accuracy is required for proper lane operation. If the RTK connection is lost, the positioning location of the vehicle could cause the vehicle to operate outside of the intended lane or straddle a lane.	The situation as described for Autoware would be like that for Apollo. The system does not monitor the accuracy of the position. Once the position is deemed "GOOD," which is identified from the NovAtel system as INS_SOLUTION_GOOD, the indicator for the Apollo localizer turns GREEN and is ready for operation. If RTK is lost during an automated drive, the safety driver will take control of the vehicle before the vehicle begins to drift out of the lane. The dash light will indicate that the NovAtel system no longer has a fix and indicate the safety driver should be ready to take over.	TRC has added a software heartbeat signal monitoring software. This checks all primary sensors (GPS, RTK, LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This software will not allow the ADS stack to be engaged should certain checks not be met and will lead to disengagements of the ADS stack should sensors timeout. The timeouts have been chosen by TRC to be small but not lead to false positives. It should be noted that while the timeouts are small, it would still be possible for safety critical events to occur in the time frame of the timeout. This system is meant to aid safety and the safety driver but does not eliminate the requirements of the safety driver. This does not monitor the quality of the data, just that the sensor is currently active in the system. For example, this will enable the system to monitor that the camera is currently transmitting data but would not check if there is a camera blockage leading to non-useful pictures being transmitted.
3	Camera fails to provide images	▪ Power loss ▪ Hardware failure ▪ Software failure ▪ Cable failure ▪ PC processing power hang up and time out ▪ Visible obstruction	Cameras are currently only utilized in the vehicle for traffic signal state detection. Traffic signal state detection enables the vehicle to determine the state of a signal: red, yellow, or green. If the camera is not operating properly, the vehicle will not be able to detect the current light state of traffic signals.	Camera-based perception has not been implemented in the AS version of Autoware or Apollo. Both open-source Autonomy stacks utilize the cameras for traffic signal detection. The open-source community and/or Baidu have chosen LiDAR as the preferred method for object detection in both Autoware and Apollo. If the camera images fail at the onset of engagement of the Autonomy system, the by-wire control system will not engage or become enabled. Additionally, TRC has added a driver monitor dash light that enables the driver to see some safety critical information. This is intended to allow the driver to see the current detected traffic signal state (if any).	TRC has added a software heartbeat signal monitoring software. This checks all primary sensors (GPS, RTK, LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This software will not allow the ADS stack to be engaged should certain checks not be met and will lead to disengagements of the ADS stack should sensors timeout. The timeouts have been chosen by TRC to be small but not lead to false positives. It should be noted that while the timeouts are small, it would still be possible for safety critical events to occur in the time frame of the timeout. This system is meant to aid safety and the safety driver but does not eliminate the requirements of the safety driver. This does not monitor the quality of the data, just that the sensor is currently active in the system. For example, this will enable the system to monitor that the camera is currently transmitting data but would not check if there is a camera blockage leading to non-useful pictures being transmitted. Additionally, TRC has added a driver monitor GUI that enables the driver to see some safety critical information. This is intended to allow the driver to see three key ADS stack statuses at once: the current engagement state of the vehicle, the current detected signal state of the traffic lane, and the currently active ROI box.
4	LiDAR fails to provide raw point cloud	▪ Power loss ▪ Hardware failure ▪ Software failure ▪ Cable failure ▪ Visual blockage ▪ Failure to properly clean LiDAR	LiDAR is currently only utilized for detecting roadway objects. If LiDAR fails, the vehicle has no means of detecting objects around it. The vehicle could unintentionally hit another object.	If there is a loss of LiDAR point cloud, the vehicle will not automatically come to stop. The DreamView viewer will illuminate a red or failed status for the perception module. Loss of LiDAR point cloud will require safety driver intervention. If LiDAR data fails at onset of engagement of the Autonomy system, the by-wire control system will not engage or become enabled. The safety driver has been instructed to not rely on the LiDAR for perception and to actively brake if they feel the vehicle is not slowing down for a	TRC has added a software heartbeat signal monitoring software. This checks all primary sensors (GPS, RTK, LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This software will not allow the ADS stack to be engaged should certain checks not be met and will lead to disengagements of the ADS stack should sensors timeout. The timeouts have been chosen by TRC to be small but not lead to false positives. It should be noted that while the timeouts are small, it would still be possible for safety critical events to occur in the time frame of the timeout. This system is meant to aid safety and the safety driver but does not eliminate the requirements of the safety driver. This does not monitor the quality of the data, just that the sensor is currently active in the system. For example, this will enable the system to monitor that the camera is currently transmitting data but would not check if there is a camera blockage leading to non-useful pictures being transmitted.

	Failure Mechanisms	Potential Causes	Impact	Apollo Mitigation Strategy	Autoware Mitigation Strategy
5	Dedicated Short Range Communication (DSRC)/Cellular Vehicle to Everything (C-V2X) failure	▪ Power loss ▪ Hardware failure (Tx or Rx side) ▪ Software failure (Tx or Rx side) ▪ Cable failure (Tx or Rx side)	The vehicle software stack does not currently utilize DSRC. This would only result in a loss of data once the DSRC is installed (C-V2X failure has a similar impact if installed).	Apollo does not currently make use of DSRC or C-V2X technology.	Autoware does not currently make use of DSRC or C-V2X technology.
6	Computer failure	▪ Power loss ▪ Hardware failure ▪ Software failure ▪ Processing timeout leading to stack failure	Any computer issue would result in the ADS stack becoming non-operational. The safety driver would need to retain control of the vehicle.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
7	DataSpeed failure	▪ Power loss ▪ Hardware failure ▪ Software failure ▪ Cable failure ▪ CAN failure	DataSpeed is the communication key between the aftermarket components added for the ADS stack and the OEM systems. Should DataSpeed fail, the ADS stack would effectively be non-operational as the stack would have no means of controlling vehicle motion.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. In addition, should the DataSpeed fail in an active way (e.g., apply throttle) there is a hard kill switch that will sever power and restore control to the safety driver.
8	Network switch failure	▪ Power loss ▪ Hardware failure ▪ Software failure ▪ Cable failure	The ADS stack utilizes a network switch for communication with a subset of sensors, specifically the GPS. A failure in the network switch would eliminate communication between the sensors and the Spectra computer. Effects would be denoted under the appropriate sensor loss categories.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	TRC has added a software heartbeat signal monitoring software. This checks all primary sensors (GPS, RTK, LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This software will not allow the ADS stack to be engaged should certain checks not be met and will lead to disengagements of the ADS stack should sensors timeout. It should be noted that while the timeouts are small, it would still be possible for safety critical events to occur in the time frame of the timeout. This system is meant to aid safety and the safety driver but does not eliminate the requirements of the safety driver.
9	On-Board Unit (OBU) is hacked and provides false information to the system	▪ Unit is hacked due to insufficient protection from digital intrusion	There is currently no OBU on the vehicle nor does the current ADS stack employ OBU functionality. It remains a possibility that an OBU could be hacked, but impact on the system is not immediately clear given that the vehicle does not employ OBU functionality.	Apollo does not currently make use of DSRC or C-V2X technology.	There is no current mitigation strategy in place for this failure mode. However, since the vehicle ADS does not utilize the DSRC/C-V2X data for navigational decisions, a failure would only result in data loss. Data loss will be mitigated by frequent changes in hard drives and uploading to a cloud storage location. This limits potential data loss to a single day of data collection.
10	Adverse weather	▪ Moderate to heavy rain ▪ Snow ▪ Fog ▪ Ice	Adverse weather impacts could range from no impact on the vehicle to rendering the ADS stack non-operational. Adverse weather would primarily affect the system through reducing the effectiveness of the vehicle motion controller or by reducing the effectiveness of the sensors. The vehicle motion controller is tuned for vehicle motion under dry operations and a change in how the vehicle operates within an environment would reduce the effectiveness of the controller to properly actuate the system.	Neither Autoware nor Apollo understands weather scenarios. It would be incumbent on the safety driver and ADS operator to recognize ADS failures and take control of the vehicle manually.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. If adverse weather is occurring, the vehicle could be driven manually (Sensor Mode) or with the ADS stack engaged but human-driven (Shadow Mode) to collect data without exposing the deployment to the risks presented by the ADS in adverse weather.
11	Signal Phase and Timing (SPaT) or MAP failure	▪ Power loss (roadside unit [RSU] or OBU side) ▪ Hardware failure (RSU or OBU side) ▪ Software failure (RSU or OBU side) ▪ Cable failure (RSU or OBU side)	The vehicle does not currently employ the use of SPaT or MAP messaging. A failure to receive these messages would only result in a data loss with no effect on the system.	Apollo does not currently make use of DSRC or C-V2X technology.	There is no current mitigation strategy in place for this failure mode. However, since the vehicle ADS does not utilize the DSRC/C-V2X data for navigational decisions, a failure would only result in data loss. Data loss will be mitigated by frequent changes in hard drives and uploading to a cloud storage location. This limits potential data loss to a single day of data collection.

	Failure Mechanisms	Potential Causes	Impact	Apollo Mitigation Strategy	Autoware Mitigation Strategy
12	Vehicle operator failure	▪ Distraction of operator ▪ Inadequate driver training ▪ Inadequate ADS stack training ▪ Overburden of operations	Vehicle operator failure could result in vehicle crashes. Drivers must be trained in the system to know vehicle trouble areas and how the system properly engages/disengages.	Research and Development (R&D) automated platforms, like manually driven vehicles, rely on attentive drivers to operate in a safe manner. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
13	ADS stack disengages unexpectedly	▪ Poor ADS stack design leading to disengagement notification failure ▪ Failure in audio and visual alert system ▪ ADS stack times out during operation	The vehicle stack has demonstrated that it will disengage without warning or notification to the driver. The stack disengaging unexpectedly could result in the system being placed back into manual control at inopportune times resulting in potential crashes.	It is anticipated Apollo would behave in a similar manner. R&D automated platforms, like manually driven vehicles, rely on attentive drivers to operate the vehicle in a safe manner. It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
14	Vehicle fails to detect object	▪ LiDAR failure ▪ Inadequate object detection algorithm ▪ Inadequate object trajectory projection	Should the system fail to properly detect an object, the system could crash into said object if it were in the vehicle path.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
15	Failure to react to stop/yield signs	▪ Traffic sign not programmed properly into high-definition (HD) map. This can either be a failure to put the traffic sign into the map or a failure in associating the traffic sign with the proper lane segments ▪ ADS stack failure ▪ Localization failure	Failure to properly follow rules of the road as indicated by local traffic control devices could result in vehicle crashes.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
16	Failure to react to traffic signals	▪ Traffic signal not programmed properly into HD map ▪ Camera failure ▪ ADS stack failure ▪ Localization failure ▪ States of traffic signals associated with incorrect lane ▪ ROI box location failure	Failure to properly follow rules of the road as indicated by local traffic control devices could result in vehicle crashes.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
17	ADS stack will not disengage	▪ System error	The system does not disengage and attempts to make an unsafe decision or movement potentially resulting in vehicle crashes.	In either Autoware or Apollo, system overrides occur in 4 ways: 1) Apply Brake, 2) Apply Accelerator, 3) Take Control of Steering Wheel, and 4) Depress E-Stop (this procedure will cut power to by-wire system). E-Stop should be sufficient to end any action by the ADS stack, however if further problems persist, the power to the vehicle should be turned off.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. OEM systems are designed with a "brake win" strategy. Should the ADS stack not disengage, the driver will need to take control of the vehicle. Even if the ADS stack continues to request acceleration, the driver requesting braking will result in the OEM system braking. Additionally, there are power cut offs (two) available to the driver to cut power to the ADS stack should it not disengage properly.

	Failure Mechanisms	Potential Causes	Impact	Apollo Mitigation Strategy	Autoware Mitigation Strategy
18	Unexpected use of roadway by ADS vehicle causing abnormal traffic patterns (in prep stage, in use stage, or post-engagement stage)	▪ Extended use of roadway shoulder ▪ Abnormal/unexpected driving behavior of ADS vehicle ▪ Drifting of vehicle after disengagement ▪ Sudden braking or evasive steering due to false perception of object in path	Abnormal use of the roadway by the ADS vehicle could result in abnormal responses by surrounding traffic. This could result in vehicle crashes.	It is imperative for the safety driver to monitor both environmental and traffic surroundings and react accordingly, i.e., allow other vehicles to pass, or temporarily takeover manual control to drive faster until safe to reengage the ADS system. Due to the reaction when some large vehicles pass the Transit, the system will be disengaged when there is an on-coming semi or similar sized vehicle.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
19	ADS software failure	▪ Sensor failure ▪ Computer failure	The vehicle software stack could fail resulting in vehicle crashes.	In either Autoware or Apollo, system overrides occur in 4 ways: 1) Apply Brake, 2) Apply Accelerator, 3) Take Control of Steering Wheel, and 4) Depress E-Stop (this procedure will cut power to by-wire system). It is imperative for the safety driver to monitor both environmental and traffic surroundings and react accordingly, i.e., allow other vehicles to pass, or temporarily takeover manual control to drive faster until safe to reengage the ADS system.	OEM systems are designed with a “brake win” strategy. Should the ADS stack not disengage, the driver will need to take control of the vehicle. Even if the ADS stack continues to request acceleration, the driver requesting braking will result in the OEM system braking. Additionally, there are power cut offs (two) available to the driver to cut power to the ADS stack should it not disengage properly. It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
20	Hard drive failure	▪ Power supply issues ▪ Excessive vibration ▪ Exceeding temperature limits	ADS stack will stop functioning resulting in data loss.	Should a hard drive fail on the computer, the ADS stack will stop sending commands, and the vehicle begins to coast at a lower speed, and eventually, a system timeout may occur. R&D automated platforms, like manually driven vehicles, rely on attentive drivers to operate in a safe manner.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. Failure in data storage hard drives will be mitigated by frequent changes in hard drives and uploading to a cloud storage location. This limits potential data loss to a single day of data collection.
21	Failure to react to speed limits	▪ Traffic speed limit not programmed properly into HD map ▪ ADS stack failure ▪ Localization failure ▪ Autonomy Parameter file edit error	This can cause the vehicle to operate at inappropriate speeds either too fast or too slow for the local traffic conditions.	If traffic control signs (stop, yield, speed limits, etc.) are not properly identified within the HD map, the ADS stack will not react appropriately. R&D automated platforms, like manually driven vehicles, rely on attentive drivers to operate the vehicle in a safe manner.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.
22	Failure to slow sufficiently or slow too much when going into tight curve or blind hill	▪ Speed controller is not tuned sufficiently or does not have an adequate ability to be tuned	This can cause the vehicle to operate at inappropriate speeds either too fast or too slow for the local traffic conditions.	R&D automated platforms, like manually driven vehicles, rely on attentive drivers to operate the vehicle in a safe manner.	It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.

3.1.1 System Safety and Threats

3.1.1.1 Sensor Failure Impacts

Sensors are the sole method for a vehicle to perceive the world around it. If even one sensor does not communicate the information correctly, then it could impede the vehicles. Sensor failures can occur at two critical stages: hardware or communication. Hardware failures would occur if there were a mechanical failure in the sensor, power loss, or internal processing does not behave as desired. A few examples include the LiDAR rotating mechanism failing, NovAtel antenna becoming unplugged, or an error in the NovAtel software not fusing the IMU/GNSS/RTK information correctly. Sensor communication failures would prevent the sensor from giving the information to the computer such as a cable failure. Examples of this would include camera fails to provide the images to the computer, the RTCM messages are not received by NovAtel, or the OBU is not able to receive/transmit messages.

Mitigation of these impacts include monitoring of the sensors and a safety driver. TRC has added a software heartbeat signal monitoring software to Autoware, and a similar system is included in Apollo. This checks all primary sensors (GPS, RTK, LiDAR, cameras) to ensure that the sensors are currently functioning and transmitting data. This sensor monitoring checks for functionality to confirm the communication and base level data for all primary sensors. This will not allow the ADS stack to be engaged if certain checks are not met and will disengage the software upon timeout. Additionally, both platforms have driver monitor GUI that enables the driver to see some safety critical information. This is intended to allow the driver to see the current ADS status.

The second major mitigation includes a project team safety driver and a passenger ADS operator. It is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. The ADS operator is constantly monitoring the system health and data collected leaving complete ability for the safety driver to be at the ready to take control should action be required.

3.1.1.2 Environmental Impacts

Environment can lead to obscured visibility from sensors, reduced control of the vehicle, and loss of localization. Some examples of environmental events include a moderate to heavy rain, snow, fog, ice, heavy cloud cover, buildings or roadway blocking the view of the sky, or salt/water spray from the road.

Adverse weather impacts could range from no impact on the vehicle to rendering the ADS stack non-operational. Adverse weather would primarily affect the system through reducing the effectiveness of the vehicle motion controller or by reducing the effectiveness of the sensors. The vehicle motion controller is tuned for vehicle motion under dry operations and a change in how the vehicle operates within an environment would reduce the effectiveness of the controller to properly actuate the system.

To reduce impact of the environment, it is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. If the weather conditions do not allow for adequate takeover time or are challenging to operate for a human driver, then the ADS stack will not be given control of the vehicle. The safety driver and ADS operator will also make a judgment call if the vehicle can be operated—even if manually—in the adverse conditions. It is important to capture the data during these weather conditions so that future development can be done in this area.

These operating guidelines are summarized in TRC and OU SOPs, which must be understood and used by their respective operators for the public road deployments. TRC and OU SOPs will be updated as needed and posted to project files for documentation.

3.1.1.3 Processing and Control Malfunction Impacts

The processing and control portion of the ADS include the computer, where all the sensors are connected and processed, and the PACMod (Apollo)/DataSpeed (Autoware) Drive-By-Wire (DBW) Controller, where the control commands are received and used to manipulate the vehicle's stock actuators. Causes of failure in either of these could be power loss, hardware failure, software failure, or communication loss.

Any major computer issue would result in the ADS stack becoming non-operational and data to stop being collected. Sometimes minor issues in the software can cause the ADS stack to disengage suddenly. The computer is also responsible for sensor processing/fusion, and a failure here would impact the correct decision making, path planning/following, or object detection and response. This would cause inappropriate driving behavior. A DBW system failure in the ADS stack would most likely prevent the actuators from being controlled by the ADS stack, effectively causing a disengagement. There is a very unlikely chance that the DBW system would fail in a way that would publish incorrect values to the actuators and cause inappropriate driving behavior. Autonomous vehicles (AVs) can face other types of sensor failures resulting in the following:

Perception Error

The perception layer is responsible for acquiring data from multiple sensing devices to perceive roadway/environmental conditions for real-time decision making. Hardware, software, and communication are the three major sources of perception errors. The perception system heavily relies on sensing technology; therefore, the perception errors may come from the hardware including sensors.

Decision Error

The decision layer interprets all processed data from the perception layer, makes decisions, and generates the information required by the action layer. Situational awareness serves as the input of the decision-making system for short-term and long-term planning. The decision errors mainly come from the system or human factors.

Action Error

After receiving the command from the decision layer, the action controller will further control the steering wheel, throttle, or brake to change the vehicle direction, accelerate, or decelerate. In addition, the actuators also monitor the feedback variables, and the feedback information will be used to generate new actuation decisions.

Like traditional driving systems, action errors due to the failure of the actuators or the malfunction of the powertrain, controlling system, heat management system, or exhaust system may rise to safety problems. However, a human driver would be able to identify these types of safety issues while driving and pull over within a short response time. However, the vehicle learns in these scenarios and responds to this low frequency, but fatal malfunctions of major vehicular components would be challenging to the full automation driving system.

Further, according to the crashes related to AVs reported by the State of California Department of Motor Vehicles, most of the crashes related to the AVs are caused by the other parties on a public road. For example, vehicles, bicyclists, and angry or drunk pedestrians who share the same road with the AVs may behave abnormally, which is difficult even for a human driver to handle.

In addition to the causes of the sensor failure, there are several impacts that can result from such an occurrence. This includes missing detection of objects, traffic signals/signs, lack of localization, or data loss.

To mitigate such failures, it is incumbent on the project team safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. Both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location. In addition, should the DBW system fail in an active way (e.g., apply throttle) there is a kill switch that will sever power and restore control to the safety driver.

Failure in data storage hard drives will be mitigated by frequent changes in hard drives and uploading to a cloud storage location. This limits potential data loss to a single day of data collection.

3.1.1.4 Vehicle Operator Failure or External Conditions Impacts

The vehicle operator has an essential role in the safety of the vehicle as the last line of defense if the vehicle behaves poorly. The vehicle operator's role is to constantly monitor the vehicle's surroundings and its trajectory and decide whether it is appropriate to take over. Potential causes of a vehicle operator failure include distraction of operator, need for additional training, and overburden of operations. A related failure is that the way the operator must use the roadway to activate the ADS may cause abnormal traffic patterns. These risks include extended use of a roadway shoulder to troubleshoot or enable the ADS stack, the ADS operation differs from natural human driving so surrounding vehicles may not expect its behavior, and the vehicle drifting after disengagement prior to the vehicle operator correcting the course.

Project team operator failure could result in vehicle crashes. Drivers must be trained in the system to understand vehicle platform capabilities/challenges and how the system properly engages/disengages. TRC and OU have developed a targeted ADS safety driver training program to ensure that any vehicle operator is prepared for on-road deployment. In addition, there is an ADS operator who is responsible for all non-safety critical actions, easing the burden on the driver. The ADS operator can provide valuable input to the safety driver by alerting of a change in ADS state and monitoring the safety driver to ensure proper engagement.

The impact of abnormal roadway use by the ADS vehicle could result in abnormal responses by surrounding traffic. This could result in vehicle crashes occurring. To mitigate this, it is incumbent on the safety driver and ADS operator to recognize ADS failure and take control of the vehicle and operate the vehicle manually. It is critical to project safety that both the safety driver and ADS operator have been trained and have experience testing the platform in a controlled environment testing location.

Some examples of the external conditions that could be tested include challenging roadway geometry, where there may be stretches of roadway that the ADS may disengage, and areas where severe incident or hazardous materials (HAZMAT) situations have occurred. Additionally, the deployment team will not be testing under any adverse weather scenarios. TRC will be applying its vehicle and driver safety protocols during these conditions.

3.1.1.5 Operational and Functional Safety Impacts

According to the definition in ISO 26262, functional safety requirement is a safety requirement implemented by a safety-related system or technologies to achieve or maintain a safe state for the item considering a determined hazardous event. Unforeseen events may cause the system to become dysfunctional.

Apart from the external conditions, the vehicle may have safety risks due to system failure reasons, such as software malfunction (unintended braking, automatic emergency braking [AEB]), hardware malfunctions (failure in chip, processor), electrical power steering, collision avoidance, electronic park brake, and airbag failure-unintended deployment during normal operation. Such events can cause functional safety issues or harm the driver/participants and road users. Each of these malfunctions has different risk severities and impacts which are analyzed in the next sections.

This section discusses safety scenarios of malfunction, installation, and the provision of wrong information that cause the applications not to provide notifications in a timely manner, or, in areas with inadequate cellular coverage, insufficient communications to the vehicle. Passenger vehicles may attempt to communicate via both DSRC and C-V2X in the corridor.

Safety Hazards caused due to Automated Driving System Application are:

- Vehicle does not perceive an object (e.g., pedestrian, bicyclist, or animal)
- Vehicle does not react to another vehicle
- Vehicle loses localization (unintended lane departure)
- Not reacting to stop signs and yield signs
- Not reacting to traffic signals
- Vehicle does not give control back to the driver
- Increased usage of shoulder before test prep (vehicle idling on the shoulder while operator loads routes)
- Vehicle is hit by another vehicle while on route
- Sensor malfunction

An ADS is only able to perceive and react to hazards if its sensors and processing work reliably. Therefore, any malfunction of the sensing devices may lead to safety risks of various degrees of severity, controllability, and exposure.

3.1.1.6 Institutional Review Board Oversight Impacts

The Institutional Review Board (IRB) has reviewed the project's research protocol and determined that project team operators are not human research subjects since they are TRC and OU employees and staff. Therefore, there is no need to have an Informed Consent Document be presented to the project team safety drivers or ADS operators. An instruction sheet containing operating instructions about the vehicles and what to do in case of a safety problem will be presented to the employees. This document is instructional documentation and does not require any consent or signature from the drivers. No participants are associated directly with this project except the safety drivers and ADS operators.

TRC/OU will prepare the driver training materials which will include driver responsibilities and limitations of the equipment, as well as what to do in case of an equipment malfunction or a crash. The driver training is an important mitigation strategy and is the fallback to any system difficulties that are not circumvented by electric and electronic (E/E) subsystems fail-safe, warning, and control systems. Survey questions will be completed by the project team drivers to document their driving experience of the ADS vehicles. The driver training process and procedures are included in TRC and OU SOPs.

3.2 Risk Assessment

Risk analysis follows three steps: identification, evaluation, and mitigation of risks, using an adapted methodology of the ISO 26262 ASIL Standards for hardware and software development and design. The risk classification scheme applies ratings for Severity, Exposure, and Controllability based on operating scenarios that have been lumped into the above categories. To complete the risk analysis, the worst-case outcome has been considered within each category. This differs from a traditional ASIL rating because each individual cause and the risk it creates are not considered, simplifying the process to be more relevant to the scope of work for this project.

The project team examined all safety scenarios related to the vehicle functional and operational requirements and developed a Risk Assessment Matrix. The ConOps, System Requirements, DPP, and DMP documents provide guidance regarding security and privacy, as well as mitigation plans for security breaches for confidentiality, integrity, and availability, along with the potential threats. There are four ratings (A, B, C, and D) identified which will necessitate additional planning around the safety operational plan in Section 4. Risks identified as QM, or "Quality Management," do not require specific mitigation measures as they only pose risk to the project's goals and are handled by normal quality management practices. For those risks, quality management practices to be performed are described in Section 4 and include provisions for equipment procurement, device installation, inclusion of a fail-safe system mode, quality training, safety reviews, and safety incident reporting.

Safety risks that are determined to be D have the highest safety risk and need the highest level of mitigation measures, while those that receive ratings of A have the lowest level of testing requirements.

The following three classes of attributes determine a risk rating:

Classes of Severity

- S0: no injuries
- S1: light and moderate injuries
- S2: severe and life-threatening injuries (survival probable)
- S3: life-threatening injuries (survival uncertain), fatal injuries

Classes of Probability of Exposure

- E1: very low probability
- E2: low probability
- E3: medium probability
- E4: high probability

Classes of Controllability

- C1: simply controllable
- C2: normally controllable
- C3: difficult to control or uncontrollable

In addition to these classes, the project team used classes of S0 and C0 for instances when the integrity level would be of inconsequential severity (S0) or insignificant to control (C0). It is a combination of these attributes that results in the combined risk scores. Analysis of each of the identified safety scenarios and the level of severity, exposure and controllability was conducted using the matrix shown in Table 3-2, which illustrates how the attributes are considered collectively to develop the integrity level.

Table 3-2. Automotive Safety Integrity Level (ASIL) Risk Level Determinations

Severity	Probability of Exposure	C1 Controllability	C2 Controllability	C3 Controllability
S0	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	QM
	E4	QM	QM	QM
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	E1	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	E1	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

Source: ISO 26262

The ASIL attributes and ratings shown in Table 3-2, are generally very broad. The project team developed modified rating rules which they used to better classify their project risks according to the combined risk attributes. These modified ratings provide granular description of the various severity, exposure, and controllability attributes for each identified risk and rolls them up to the highest-level ratings for better application to the deployment. The Severity, Exposure, and Controllability Rule Ratings shown in Table 3-2 were applied to the safety risks identified in Table 3-1 to help in the assessment of the values in the final score of each risk as depicted in Table 3-3. Each safety risk is rated with a rating rule and modified ASIL scoring. Table 3-3 shows the results of the safety risk assessment process, detailing each safety scenario identified, and the ASIL dimensions assigned with their resulting ASIL rating.

Table 3-3. Safety Risk Ratings Matrix

ID	Failure Mechanism	Severity	Exposure	Controllability	ASIL
1	GPS fails to provide location	3	1	1	QM
2	RTK correction loss	1	4	1	QM
3	Camera fails to provide images	3	4	1	B
4	LiDAR fails to provide raw point cloud	4	2	1	QM
5	DSRC/C-V2X failure	0	1	3	QM
6	Computer failure	3	4	3	D
7	DataSpeed failure	3	1	3	A
8	Network switch failure	3	2	2	QM
9	OBU is hacked and provides false information to the system	0	1	3	QM
10	Adverse weather	3	1	1	QM
11	SPaT or MAP failure	0	4	1	QM
12	Vehicle operator failure	3	1	1	QM
13	ADS stack disengages unexpectedly	3	4	3	D
14	Vehicle fails to detect object	3	4	2	C
15	Failure to react to stop / yield signs	3	4	1	B
16	Failure to react to traffic signals	3	4	1	B
17	ADS stack won't disengage	3	1	2	QM
18	Unexpected use of roadway by ADS vehicle causing abnormal traffic patterns (in prep stage, in use stage, or post-engagement stage)	3	4	2	C
19	ADS software failure	3	4	3	D
20	Hard drive failure	3	1	3	A
21	Failure to react to speed limits	3	2	1	QM

Section 4

Safety Operational Plan

TRC and OU have SOPs to guide the appropriate use of the project passenger vehicles, when the ADS software can be enabled, and how to operate it appropriately when it is engaged. More details can be found in TRC's and OU's SOPs. The respective project vehicle operators will follow their SOPs. This section of the SMP only highlights the project operating guidelines and is not a substitute for the TRC and OU SOPs. System safety is always the highest priority when the vehicle is in use. This requires an in-depth knowledge of the full system through scenario-based closed-course testing and having highly trained drivers.

The system under test is a prototype research platform and the goal of this project is not focused on the development of the ADS. The approach to achieve safety is to put sufficient safety measures around the operation of the vehicle by having an appropriate understanding of the system's limitations and have the expectation that the driver is fully in control and responsible for the vehicle's actions. In addition, having the capability to instantaneously take manual control of the passenger vehicle by the safety driver is required for this approach to be valid. Treating the ADS-equipped vehicle as a lower-level system with sufficient control will provide the most fundamental form of safety during deployments. The following paragraphs define the TRC/OU general approach to establishing a plan for determining appropriate safety measures.

Testing will take place in two environments over the course of this program. Controlled Environment Prove-out will be conducted under closed course conditions at TRC Proving Grounds and on OU private roads. Public road deployments will take place on central Ohio US RT 33 (Dublin-Marysville) and in Athens, Ohio for the Ford Fusion using Autoware platform. Other project vehicles using Apollo platform will conduct public road deployments in Athens, Ohio.

Testing that takes place on TRC Proving Grounds and OU private roads will comply with their respective Facility Operating Guidelines (FOG), a set of safety protocols established by TRC/OU to ensure safe operations on the facility. Any test plan that falls outside of the FOG will be submitted to TRC Corporate Administrative Safety Committee (CASC) for review. CASC will provide feedback on the defined test plan and determine if it can be safely carried out and may request modifications prior to approval. These tests do not require a separate SOP.

The public road testing and deployments using an active ADS require the development of a test-plan-specific SMP. The project team is responsible for identifying safety scenarios, completing a detailed risk analysis, and designing a safety operational concept. These sections of the SMP must also be reviewed and accepted by Advanced Mobility leadership prior to conducting on-road testing. Milestones will be added to the project schedule for drafting, reviewing, and finalizing the SMP.

The SMP must be reviewed and updated, as appropriate, to reflect changes that impact the test plan. The project team must first consider if the change(s) fall under one of the identified safety scenarios or if the change introduces a new one. The project team then performs a risk analysis to determine if the change(s) introduce additional failure modes. Changes that could potentially impact the SMP include, but are not limited to, any change to sensor hardware, ADS software stack, driver interface, sensor software, operating personnel, and the ODD.

It is the responsibility of the project team to ensure that a mitigation strategy developed in Section 3.2 and enumerated in Table 3-1 has been put in place for all items that have been identified in the risk analysis. The TRC and OU Project Managers are responsible for informing the appropriate project team (at a minimum DriveOhio) of the test plan, including number of vehicles and locations.

In addition to a robust SMP, TRC/OU will execute a controlled environment analysis of an ADS prior to taking it on public roads for testing. The scenarios in this analysis include both basic ADS functionality and scenarios specific to the ODD. The project team will not deploy an ADS on the road until it is comfortable with the performance of the vehicle in a controlled environment. This controlled environment testing also gives safety drivers the much-needed seat time to gain comfort in operating the ADS.

TRC and OU SOPs will be updated as needed and posted to a project file for documentation. Related documents, such as the CE Test Plans are also posted to a project file for documentation.

4.1 Equipment Procurement

The first step to addressing functional safety is to ensure that the underlying equipment has passed quality checks and is ready to be integrated into the system. This has been done by sourcing sensors from reputable companies with quality control checks internal to the supply process. In addition, the supplier/integrator chosen for this project conducts checks on the components as they are integrated into the vehicle to ensure that safety critical sensors are functioning. The vehicle platform is a commercially available vehicle, following industry standards for safety. It was passed through a multipoint inspection upon acceptance to ensure the safety of the underlying vehicle if all automation is disengaged. In addition, the supplier/integrator validates the final system level results when performing final calibration of the system. More detail can be found in TRC and OU SOPs.

4.2 Pre-Deployment Safety Management

The SMP begins before the vehicle starts the deployment. For prototype systems, it is important that their capabilities are well understood to limit surprises on the road. To this end, extensive controlled environment work is carried out putting the vehicle in scenarios expected on public roads. The result of this creates an understanding of where the system can be safely deployed. In addition, the capabilities will be used to communicate to the project team safety driver and ADS operator.

4.2.1 Pre-Deployment Controlled Environment Testing

TRC/OU will create a controlled environment test plan to develop an understanding of the current abilities and limitations of the ADS. This testing will be done for all ADS-equipped vehicles, as well as additional testing around capabilities that are not as expected. The controlled environment testing takes a phased and categorical approach towards developing an understanding of the ADS-equipped vehicle's capabilities to operate safely on public roads. The scheme is structured to expose the ADS-equipped vehicle to progressively complex situations, test the ADS's response, and inform the safety operator of expected behavior in a controlled environment setting. Such an evaluation will help assess knowledge gaps, functionality gaps, and increase the safety driver and ADS operator's confidence before deployments on public roads and in challenging environments. Categories tested include:

- Initialization and Handover (Engage/Disengage)
- Localization Accuracy
- Waypoint Following
- Route Planner
- Lane Keeping
- Detect and Respond to Speed Limit Changes
- Detect and Respond to Stop Signs
- Detect and Respond to Traffic Signals
- Detect and Respond to Obstacles
- Advanced Lane Keeping and Lane Changes
- Intersection Approach and Departure

4.2.1.1 Controlled Environment Test Plan for Apollo

TRC

TRC will complete the CE test plan on both AS's Apollo platform on the Transit vans. The testing process will document the functional capabilities that the vans are able to meet. Each test scenario will have several variations to attempt to collect the most important challenges that are currently anticipated. The testing is currently broken up into testing outside of intersections (Table 4-1) and in intersections (Table 4-2). A separate document with the detailed CE test plan is prepared and posted to project files. The CE test plan will provide important safety information to the project team safety driver and ADS operator of the kind of situations to be aware of. In addition, if significant problems are found an engineering review will be done to determine if the software should be modified to provide appropriate response to a situation, can continue with monitoring, or the system must be disengaged around such a situation.

Table 4-1. Intersection Testing

SITUATION	1	2	3	4	5
General Driving	**Road Geometry**	**Speed (MPH)**			
	Straight	Range[35,55]			
Responding to Traffic Signs	**Road Geometry**	**Sign**			
	Straight	Increase/decrease speed and stop			
Making a Lane Change	**Road Geometry**	**Speed (MPH)**	**Maneuver**		
	Straight	Range[35,55]	Lane Change[Left, Right]		
General Driving + Stopped Obstacles	**Road Geometry**	**Speed (MPH)**	**Stopped Obstacles**		
	Range[Straight, Curved]	Range[35,55]	POV[Pedestrian, Bicyclist, Soft car]		
Car Following [Single Lane]	**Road Geometry**	**SV Speed (MPH)**	**POV [Type, Speed-Profile]**		
	Straight	Range[35,55]	POV[Car, Range[0,55],[Constant, Accel+Decel]]		
	Straight	Range[35,55]	(Targeted Naturalistic Scenario) Follow Lead Car with consecutive acceleration, deceleration events.		
Car Following [Multi-Lanes], Multi-Obstacles	**Road Geometry**	**SV Speed (MPH)**	**POV [Type, Speed-Profile]**	**POV Maneuver**	**Reveals**
	Straight	Range[35,55]	(Targeted Naturalistic Scenario) Interact with car that performs a variety of cut-in, cut-out maneuvers with ADS in a driving lane.	Lane Change[Cut-In,Cut-Out]	Empty Road
Cut-out (POV) with Late Reveal Stationary Obstacle (SOV)	Straight	Range[35,55]	(Car, Range[35,55], Constant)	Cut-Out-Constant Speed	Stopped Vehicle

Table 4-2. Non-Intersection Testing

SITUATION	1	2	3	4	5	6
	Speed(mph)	**Type of signal**	**SV turn**	**SV Type of lane**		
	15-35	Stop sign	Left, Right, Straight	Left, Right		
General Driving	15-55	Red,Green,Yellow	Left, Right, Straight	Left, Right, Middle		
	Speed(mph)	**Type of signal**	**SV turn**	**SV Type of lane**	**POV Lane**	**POV Turn**
	15-35	Stop sign	Left, Right, Straight	Left, Right	Left, Right	Left, Right, Straight
Driving with opposing traffic	15-55	Red,Green,Yellow	Left, Right, Straight	Left, Right, Middle	Left, Right, Middle	Left, Right, Straight
	Speed(mph)	**Type of signal**	**SV turn**	**Type of lane**	**POV Lane**	**POV Turn**
Driving with cross traffic	15-35	Stop sign	Left, Right, Straight	Left, Right	Left, Right	Left, Right, Straight
	Speed(mph)	**Type of signal**	**SV turn**	**Type of lane**	**POV Lane**	**POV Turn**
	15-35	Stop sign	Straight	Right, Left	Right, Left	Left, Right, Straight
Car following in straight line	15-55	Red,Green,Yellow	Straight	Right, Middle	Right, Middle	Left, Right, Straight
	Speed(mph)	**Type of signal**	**SV turn**	**Type of lane**	**Direction of pedestrain**	
	15-35	Stop sign	Right,Left	Right, Left	Parallel to SV start lane farside/nearside	
Driving with pedestrian crossing	15-55	Green	Right,Left	Right, Left	Parallel to SV start lane farside/nearside	
	Speed(mph)	**Type of signal**	**SV turn**	**Type of lane**	**Direction of pedestrain**	**POV Lane**
Driving with opposing traffic and pedestrian	15-35	Stop sign	Left	Left	Parallel to SV start lane nearside	Left, Right
	15-55	Green	Left	Left	Parallel to SV start lane nearside	Left, Right, Middle

Ohio University

The IDEAS Automated Road Vehicle will be tested on a private road within a controlled environment to test the operation of Apollo.

The goal of the controlled environment test plan is to verify that the Apollo software can operate in fully autonomous mode on a private road. OU's SOP will be followed according to the 01112022 version. Additional troubleshooting assistance is available through the Passenger Vehicle Safety Management Plan (SMP) Table 3-1.

Before driving on selected private road (the Ridges loop) pre-driving safety checks will occur:

1. Pre-driving safety checks:
    a. Follow OU SOP for vehicle setup (from shore to car power and start-up sequence)
    b. Sensors: Verify operation of the LiDAR, cameras, GPS, and RADAR system
        i. LiDAR: verify the environment around the van is correct and the orientation is correct
        ii. Cameras, do both cameras see the correct direction and are displaying images in RViz or similar
        iii. LiDAR + Camera calibration: Run the Autoware LiDAR and Camera overlay process in RViz
        iv. RADAR: Ensure that objects are detected in front of the vehicle and reflect the environment (DreamView)
        v. GPS: Check that the GPS system is in RTK mode and receiving correction
    c. Drive-by-wire
        i. Verify operation of the DBW system by using the Logitech controller program and checking for manual control of braking, steering, and throttle systems
    d. Maps
        i. Ensure that the maps are available and loaded by the Apollo system

Steps of the CE test plan:

1. Perform manual driving/Non-automatic mode: Collect data of all cyber channels using the Ridges loop in manual operation at least twice (controlled speed limit 20 mph or under)
2. Play back data of 1-2 loops hand driven in Apollo simulation
3. Identify any problems and disengagements in simulation
    a. For the data collected, if more than 3 disengagements happen, find the cause and notify AutonomuStuff and/or note the region for likely manual take over alternative using the data collected and simulations to resolve issues (i.e., Update the maps, software, etc.) and lock in the data and machine when a functioning combination is identified
4. Perform automation test on the 0.5-mile loop in a clockwise direction (requested 20 mph operation)

Outcome: Apollo is utilizing the sensors and maps to fully self-drive on private road indicating proper functionality of the system

Extra validation to verify the maps and public road operation (not necessary):

1. Ensure the system can identify Stop signs and mapped streetlights

2. Ensure the system can identify other vehicles and pedestrians. The OU CE Test Plan is prepared and posted to a project file for documentation.

4.2.1.2 Controlled Environment Test Report

TRC and OU prepared controlled environment test reports which captured the test plan, findings, and conclusion from the controlled environment testing. These reports are posted in a project file.

4.2.2 Pre-Trip Checklist

Routine maintenance will be done on the vehicle to ensure it continues to operate at the expected level. In addition, the following evaluation will be carried out before taking the project vehicle on public roads with ADS active: tire condition, all sensor channels coming through, RTCM corrections are being received, RTK accuracy established, and visual inspection of localization. More details can be found in the TRC and OU SOPs.

4.2.3 Unfreeze Software Controlled Environment Testing Process

Once the Autoware and Apollo software is frozen, the major tuning of each system will be considered done. In some cases, it may be necessary to unfreeze the software to correct something discovered in CE testing or on deployment. However, not all changes will be considered to unfreeze the software. Any change to the software will undergo an engineering review at TRC and OU and will require that aspect of the ADS to undergo CE testing again. Examples that could cause the ADS to need further testing include, but are not limited to, change of sensor, significant increase in processing required, or changing the configuration file to make the system less conservative. The exact nature of the change will be taken into account and investigate what aspects of the CE testing it may affect. For example, if the following distance is decreased in the configuration file, the engineering review may determine that only a subset of the AEB testing needs to be redone. Any unfreeze of the software will require a review and determined of the specific CE testing needs and be documented by TRC and/or OU, depending on the project vehicle. The required CE test plan and testing by TRC and OU were conducted and documented before the project vehicles are permitted on public roads for data collection.

4.3 Operator Training and Deployment

Understanding the ADS-equipped vehicle's capabilities will only be effective if there are properly trained project team drivers and operators who can enable and disable the system in the correct circumstances and take control when necessary. To achieve a safe operation of the vehicle, all safety drivers and ADS operators will be trained. A driver training plan has been developed for this very purpose. Its goal is to provide safety drivers with an understanding of current automation capabilities and training to improve attention and takeover capabilities. This includes training to handle vehicles at near limit, as well as an in-depth understanding of the software and its limitations. The training will take place in a controlled environment and give the drivers the opportunity to see at what point the vehicle begins behaving dangerously and when to take over before a dangerous situation occurs. To achieve this in a safe situation, soft targets will be used to allow safety drivers to see the limit of vehicles and at what point to take over. In addition, as a part of the training they will operate the vehicle when it is programmed to take incorrect actions (i.e., suddenly veering), demonstrating appropriate takeovers. In addition to the safety driver, the

CDM Smith

ADS operator will be responsible for monitoring the ADS health, engaging the system, and ensuring data is being collected.

TRC and OU have the responsibility to train their project team operators per their respective SOPs. This training will be completed and documented before the project vehicles are permitted on public roads. TRC and OU prepared driver training plans and posted these documents in a project file.

4.3.1 Transportation Research Center Vehicles

The two AS Transit vans will only be driven by TRC employees. TRC will select designated project team ADS operators and safety drivers that must go through the following training process before they will be allowed to drive the vehicle on road. First, it is essential that both the safety driver and the ADS operator are familiarized with the vehicle. The safety driver and ADS operator do not need to be fully trained in both positions to do their individual function but must understand the different roles and responsibilities. Both roles need to have at least a full day of operating the van from the prospective location in a CE. Each role much have experience with steady state driving, traffic lights, stop signs, stopped vehicles, vehicles crossing into path, and pedestrians to understand the system's nominal behavior in each of these situations. The ADS operator must be well versed in the ADS including, engaging the system, understanding all the alerts that are provided on the dashboard, and monitoring for faults and failed detections. Second, the safety driver must have passed TRC Inc.'s Level 2 driver training class. This class is optional for the ADS operator. Third, the safety driver should be familiar with AEB activation to understand the boundary of when a system can successfully break. At least 7 passes with an AEB system engaged is recommended and is optional for the ADS operator. Finally, deployment training for prototype systems will be required for both the ADS operator and safety driver, which will go over the importance of staying alert and understanding the limitations of prototype systems.

4.3.2 Ohio University Vehicle

The following steps will be undertaken for approval to act as a safety driver in the OU Driver Training Plan and Approval Process:

1. Requirements to be a safety driver:
    a. Pass the background check following Ohio University Policy 47-001: https://www.ohio.edu/policy/47-001
    b. Demonstrate operation of a vehicle by obeying posted speed limits and obeying all traffic laws for the state of Ohio
    c. Demonstrate ability to monitor the road and be ready to overtake either steering and/or brakes immediately
2. Approval process by Dr. Wilhelm:
    a. At least one training session with van running in full autonomous mode to approve foot over brake and hands over steering wheel with eyes on the road (safety driver mode)

i. During this session, the automation system will be engaged and manually disengaged by the system operator to test the driver's response both to the audible warning of the ADS operator and the vehicle conditions

b. The drivers will obey all traffic laws and stay at or under the posted speed limits.

c. The drivers will NOT be tested with dangerous situations that if control is not acquired fast enough will endanger others or the vehicle.

The final decision, active drivers, and revoking of safety driving privileges will be made and kept by Dr. Wilhelm.

4.4 Deployment Plan

4.4.1 Corrective Action Management

TRC utilizes Corrective Action Management (CAM) to report all appropriate incidents, both on TRC Proving Grounds and off. All employees are accountable for reporting incidents of various nature including safety risks. Should an incident occur, employees must report the incident to their direct supervisor and provide the details needed to complete an incident report.

Supervisors are responsible for submitting incidents into the CAM system. The intent of the CAM process is to identify improvements that can be made to prevent or reduce the chance of incident recurrence. Contacting emergency personnel always takes precedence when an incident involves injury or property damage.

4.4.2 Operational Design Domain

The ODD of the project vehicles is limited to locations with HD maps for the routes in the Athens area and as detailed in the ADS Demonstration Site Map and Installation Schedule report. The HD maps have been obtained through a third party (Mandli). These require review and testing for accuracy to ensure safe public road deployments. Outside of the HD map requirement, the vehicle can have the ADS engaged in mixed traffic and through limited intersections. Weather is considered the largest limitation of ODD as the ADS should not be engaged when road conditions are slick or could cause reduced response time. More detail can be found in the TRC and OU SOPs. A list of scenarios that are to be avoided will be enumerated in the controlled environment test report and this information will be included in each TRC and OU SOPs. An example of a scenario is intersections with other traffic that could move into the planned path of the ADS-equipped vehicle. A full list will be ready before public road deployment.

TRC and OU will work with Mandli to improve the three HD maps in the Athens area. Mandli is responsible for correcting the maps per the direction with confirmation from TRC/OU. The HD maps routes can be found in the Demonstration Site Map and Installation Schedule report. TRC/OU are responsible for the handling of the project vehicles per their SOPs.

4.4.3 Safety Driver Monitoring

The ADS is still very much a prototype system. As such, even though the system is a L3 it will be treated as L2 system and be strictly monitored by both a project team safety driver and an ADS operator. The safety driver is responsible for monitoring the roadway and taking action before a potential collision could take place. The safety driver will be trained driver with direct experience in operating the vehicle and trained specifically as a safety driver. The safety driver will monitor the vehicle for drifting toward lane lines, sudden motion changes, and potential impacts with other vehicles, vulnerable road users, or objects. The safety driver will be trained to monitor these aspects and when it is appropriate to intervene. In addition, the safety driver will monitor the vehicle's surroundings in case intervention is required. Finally, the safety driver will ensure the vehicle stays inside the ODD.

The ADS operator is another critical safety aspect to public road deployment. The ADS project team operator's task is to offload tasks that are required to operate the ADS that could take the safety driver's attention off the road. This includes engaging the ADS, monitoring system health, and ensuring the ADS understands its environment correctly (processes correct signal status, does not miss critical object detection, etc.). More details on project driver training can be found in the TRC and OU SOPs.

4.4.4 Automated Driving System Engagement/Disengagement

The final portion of the deployment plan relates to how the ADS software selects its path. The project team ADS operator is responsible for engaging the system. To improve safety, the HD maps were made to have entry points that allow for a starting location from an area where the vehicle can be parked. There will likely be time spent with the vehicle stopped for several minutes between runs, so it is important that these designated areas are used whenever possible. There are likely times that will require the vehicle to be stopped on a shoulder. This should only be done when there is sufficient space on the side of the road to safely accommodate the vehicle and the hazard lights should be activated. The ADS operator and safety driver will work in conjunction when the system is being engaged to ensure there will not be any conflicts with the surrounding traffic. Based on the day's deployment test plan, the ADS operator will select the destination and ensure the path generated is accurate and safe before final engagement of the ADS. If the ADS operator sees a reason to disengage the system, they will do so in coordination with the safety driver to ensure there is adequate takeover time available. More details can be found in the TRC and OU SOPs.

4.4.5 Human Factors Data

The deployment plan for collecting human factors data is separate from the regular data collection during automation and will focus on driver takeover situations. The same Apollo data will be collected where only a slice of time (+/- 30 seconds) of a disengagement or driver take over event occurs. The safety driver will be outfitted with eye tracking and biometric monitoring devices to identify physiological response of the human operator, what they were doing just before and after the takeover. The data collected from the vehicles and sensors will be compared using common timestamps to achieve an error < 1 second. The eye tracking device is a Tobii Pro 3, capable of determining where human eyes and head were looking at a rate of 50 Hz. The biometric sensors are provided from Zephyr to monitor breathing and heart rate at 10 Hz. The use of this project equipment will be addressed in the SOPs.

Section 5

Coordination with Other Tasks

The SMP is not a standalone document, as other project documentation provides the information for the risk analysis, and the outputs and mitigations needed to populate other documents in the project. This section identifies the coordination required with other tasks. The documents produced for the below tasks are subject to revisions as the project develops.

5.1 Concept of Operations

Safety scenarios in this SMP follow the ConOps, operational concept, and use cases developed for the passenger vehicle deployment. The ConOps lists the user needs, applications to be deployed and operational practices to be followed for the deployment. Section 4, Safety Operational Plan was developed in coordination with the proposed operational practices described in these conceptual documents for each project.

5.2 Deployment System Requirements

The System Requirements created for the ADS passenger vehicle deployment will identify and specify the requirements following established guidance such as those in the Federal Highway Administration's (FHWA) Systems Engineering for ITS. The requirements will be based on the user needs and system concept developed and documented in the ConOps. The Institute of Electrical and Electronics Engineers (IEEE) Standard 1233-1998, the IEEE Guide for Developing System Requirements Specifications, will be used as the general guide for documentation. Although the IEEE guidance allows significant flexibility in the structuring of requirements, the specification will use the common categories of functional, interface, performance, security, data, and reliability requirements.

5.3 Data Management Plan

While the SMP outlines high-level mitigation strategies for the data storing risks identified, the DMP developed for the ADS project describes how data will be collected, managed, integrated, and disseminated before, during, and after the passenger vehicle deployment. The DMP also provides detailed protection and mitigation for data risks identified to protect the privacy of the users and ensure secure operations. The DPP and DMP work to ensure that data privacy and operations are secure.

5.4 Data Privacy Plan

The DPP created for the ADS project provides guidance material regarding security and privacy for the Ohio Rural ADS deployment. The document is developed based on identifying the impacts of security breaches regarding confidentiality, integrity, and availability along with potential threats. The safety scenarios, as well as safety operational concept, were developed to protect the privacy of users, ensure secure operations, and eliminate the impact of security breaches.

5.5 Human Use Approval Summary

The Human Use Approval Summary aims to document the efforts made to ensure the protection of personal information, which is the purview of the DPP, and human safety which includes the mitigation strategies discussed in this SMP. In the passenger vehicle deployment in this project, there is no personally identifiable information (PII). ODOT staff and past practice determined that incidental video of pedestrians near the vehicle is not PII. Project team drivers and other TRC/OU staff in the passenger vehicles are employees/staff of TRC/OU and are exempt from IRB requirements. No data about the driver or passengers, either personal data or video, is being collected. Documentation submitted to the IRB at the University of Cincinnati noted that a consent form is not required for those TRC/OU employees/staff. Thus, although a Protocol document was submitted to the IRB by the project, no human use approval is required for the passenger vehicle deployment.

5.6 Driver Training Plan

The Ohio Rural ADS Project requires a Driver Training Plan for project team members involved in the deployment and it divides the efforts among three objectives. For end-users, like the passenger vehicle drivers, the emphasis will be on developing a level of comfort and understanding of the operation and messaging provided to them in-vehicle. Drivers may not be aware of the potential safety scenarios and the actions they are expected to take during emergency situations. Therefore, the mitigation strategies from the SMP will be included as part of the training plan as a key to prevent personnel injury and eliminate the potential impacts when safety risk scenarios happen. An end-user training plan will be developed, consistent with the Human Use Approval Summary that would include driver inputs from controlled environment and field deployment tests.

5.7 Stakeholder Outreach Plan

There are two stakeholder outreach groups in the Ohio Rural ADS Project: Project Stakeholders and Law Enforcement Stakeholders.

5.7.1 Project Stakeholders

Communications and engagement plan prepared by Murphy Epson include stakeholder education, as well as the identified stakeholders for the Ohio Rural ADS Project. These activities identify the participant roles and responsibilities taken during the deployment, their actions, and training requirements. Communications and outreach will be consistent with the actions described in the SMP to reduce the likelihood and potential impact of each safety scenario.

5.7.2 Law Enforcement Stakeholders

The communication and engagement plan prepared by DriveOhio and the State of Ohio Highway Patrol focus on the specific law enforcement covering the specific routes in the Athens area. ADS Demonstration Site Map and Installation Schedule Report provides route information. With the Highway Patrol as the facilitator and DriveOhio as the host, the Highway Patrol will invite all levels of law enforcement agencies to a stakeholder meeting to discuss the Ohio Rural ADS Project for passenger vehicle deployment on public roads in the Athens area. The meeting will provide information on the L3 vehicles, routes, deployment schedule and project vehicle safety and operations.

5.8 Interface Control Document

The Interface Control Document developed for the Ohio Rural ADS passenger vehicle deployment refers to the SMP to make sure all the safety risks listed in this plan are addressed while designing and testing the system and applications developed in this deployment.

Section 6

Summary/Conclusions

The SMP provides guidance material about the identification of safety scenarios and risk mitigation for the passenger vehicle deployment. The plan identifies the safety scenarios at deployment level, assesses the level of risk for each scenario, and provides a safety operational concept for high/medium risk scenarios. Safety stakeholders for each project were identified and coordination with emergency responders was incorporated in the SMP.

This document will help feed the AVPP application to operate L3 vehicles in the State of Ohio, as well as the voluntary self-assessment requested by the National Highway Traffic Safety Administration (NHTSA). Further, it is expected that this can be a living document that will be updated based on the test results and early deployment actions, ultimately feeding back into the risk mitigations and driver training plan updates.

Additional conclusions and next steps regarding safety management include:

- The project risk manager will provide guidance to the deployment team and continue to follow all scenarios. The purpose will be to document verification of safety-related requirements and to coordinate safety-related activities of all stakeholders.
- The driver training will advise participants of the safety problems that might arise and how to get aid, if needed.
- While the ConOps and System Requirements documents are finalized for this deployment, refined analysis may lead to more safety scenarios being identified. They will be rated and tracked along with those already identified. Some of the safety scenarios will be addressed by writing safety requirements and verifying designs to those requirements. They will be tracked through design and development phases of the deployment. Other hazards will require ongoing safety management through the duration of the deployment phase.
- Other ADS stacks, if used in the deployment, will be evaluated for additional risks or different required mitigations.
- The TRC and OU CE Test Reports and updated SOPs are important safety documents and available in the project files.

Appendix A

Automated Vehicle Law Enforcement Reporting Form

OHIO DEPARTMENT OF TRANSPORTATION

DriveOhio is working with industry and public sector.

As this new technology is tested and driven on Ohio's public roadway, we acknowledge that there will be interactions between automated vehicles and law enforcement. This form and database will gather and store information to help our DriveOhio team understand trends or concerns, then work better with industry and public sector.

You are reporting this type of event: *

- ☐ crash
- ☐ traffic stop
- ☐ consensual encounter

When did the event occur: Date/Time*

[ ] [ ] [ ]

[ ] : [ ]

Where did the event take place (what address, roadway milemarker, or intersection): *

[ ]

County where the event took place*

ADAMS

Driver/Operator Name*

First Name

Last Name

Vehicle License State/Number*

Describe the circumstances of the event, the interaction with the automated vehicle and the driver:*

Law enforcement officer who had the interaction

Name*

First Name

Last Name

Role/Title

Agency/Employer*

Phone

Email*

Submit Form

The Ohio Department of Transportation
1980 West Broad Street, Columbus Ohio 43223
Mike DeWine, Governor | Jack Marchbanks, Ph.D., ODOT Director | Feedback | Ohio.gov

Appendix B2
TRC ADS Grant Project Final Report

ADS Grant Project Final Report

Prepared By:

Transportation Research Center, Inc.

Prepared For:

02/19/2024

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1 System Specifications

1.1 Background

Transportation Research Center (TRC) Inc. led deployments of prototype level-3 automated vehicles in rural Ohio. The deployments were divided into two phases. The specifics of the deployment phases are provided in Table 1.

Table 1: Deployment phases in rural Ohio

TRC Deployment phase	Region	ADS stack	Platform Vehicle
Phase - 1	Central Ohio	Autoware	1 Ford Fusion
Phase - 2	Soth-east Ohio	Apollo	2 Ford Transit Vans

1.2 Desired capabilities

The system desired capabilities are dictated by the limitations of the state-of-the-art ADS platforms that can be outfitted on production vehicles, desired deployment areas, cost, and safety. Although, the intended prototype vehicle was theoretically capable of L3 driving, a trained driver accompanied by ADS safety operator was always present in the vehicle during deployment and testing. The system was expected to be operating under sub-critical driving conditions during the deployment. It was assumed that the trained driver would override the ADS under critical conditions or the vehicle's stack ADAS would ensure safety under such situations. Hence, the system was not expected to navigate under edge cases and was not expected to maneuver under critical circumstances. Similarly, publicly available ADS stacks are not capable of operating under low friction conditions including ice and snow. Table 2 has a list of desired capabilities of the ADS platform.

Table 2: ADS platform desired capabilities

General Driving	Routing based on driver supplied waypoints
	Following waypoints, speed limit, and lane center based on HD maps
	Stopping at stop-sign based on HD map
	Perform lane changes for waypoint following
	Use left and right indicators appropriately
Obstacle avoidance	Obstacle avoidance by speed adjustments[1]
Car Following	Car following using adaptive cruise control
Navigating Intersections	Traffic light detection
	Cross traffic and oncoming traffic detection and yield
	Left/right turn yield (including unprotected left)

[1] The system is not capable of discretionary lane changes to avoid obstacles.

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1.3 System Specs for Ford Fusion

The ADS platform used for the phase-1 deployment used was based on Autoware.AI. Autoware is an open-source ADS stack developed by partners of Autoware foundation. The stack used in this project was provided by the AutonomoStuff™, which is based on the open source Autoware found at autoware.ai. The core communication system used by autoware.ai is Robot Operating System 1 (ROS1).

The vehicle used is a Ford Fusion sedan. The vehicle is outfitted with sensors and Drive-By-Wire kit provided by AutonomoStuff™. The details for the sensors and other hardware are mentioned in Table 3.

The high-level architecture for the Autoware consists of the vehicle interface, map, sensing, localization, perception, planning, and control module, as shown in Figure 1. Each module has ROS nodes that subscribe and publishes topics to the core communication channel in ROScore.

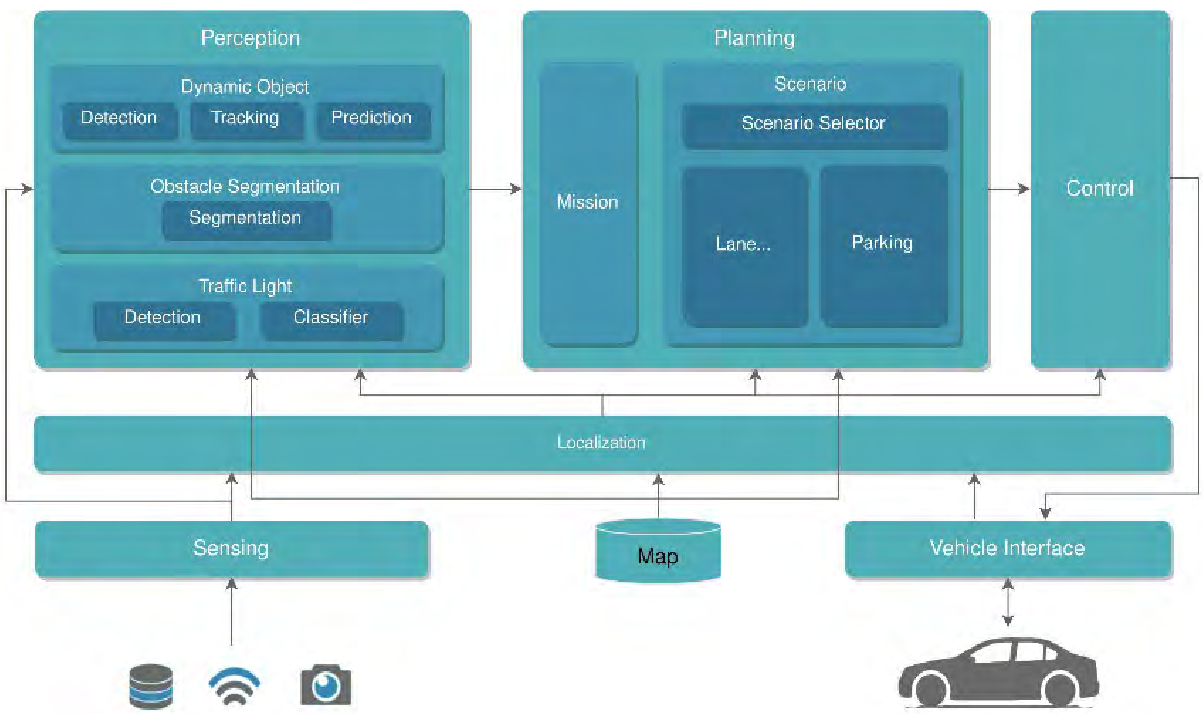

Figure 1. High Level Architecture for Autoware.AI

Table 3: Specification for the Autowar.AI Ford Fusion

Equipment	Specs	Used primarily by autoware module
Computer	Nuvo-6108GC Intel(R) Xeon(R) CPU E3-1275 v5 @ 3.60GHz Core Count 4, Thread Count 8 RAM: 32 GB GPU: Nvidia RTX2080 Super (Driver Version 460.91.03)	Compute
Lidars	VLP-32C /Lidar	Perception and classification of other agents
GPS	NovAtel PwrPak7D GNSS/INS	Localization
Control	AutonomoStuff Speed and Steering Control	Vehicle interface software
Cameras	2x Allied Vision Technologies MAKO cameras	Perception of traffic light state
RTK corrections	Cradlepoint: NTRIP corrections over internet	Localization
Radar	1. 1x Forward facing Delphi ESR radar (60m-174m range) 2. 2x Rear corner Delphi SRR2 radar (0.5-80m range)	**Radar Module was not active in the software**
Drive by wire	DataSpeed Throttle & brake by-wire controller module, steering & shifting by-wire controller module	Vehicle interface hardware

1.4 System Specs for Ford Transit Vans

The ADS platform used for Phase 2 deployment was a prototype Society of Automotive Engineers (SAE) L3 automation system. The vehicles used, the two Ford Transit Vans, were outfitted with a Hexagon PACmod drive-by-wire kit, perception sensors, Spectra-2 computer for computation, and NovAtel GNSS/INS for localization. The main control software is based on Apollo, which is an open-source control stack. It provides a set of software subsystems, such as localization, planning, perception, and control that make up the automation stack, as shown in Figure 2. To interface with the drive-by-wire, AutonomoStuff's Speed and Steering Control (SCC) software is used. Apollo uses Dreamview as human machine interface (HMI) for feeding waypoints and live visualization of different signals. Figure 3 shows a view of this HMI visualizer.

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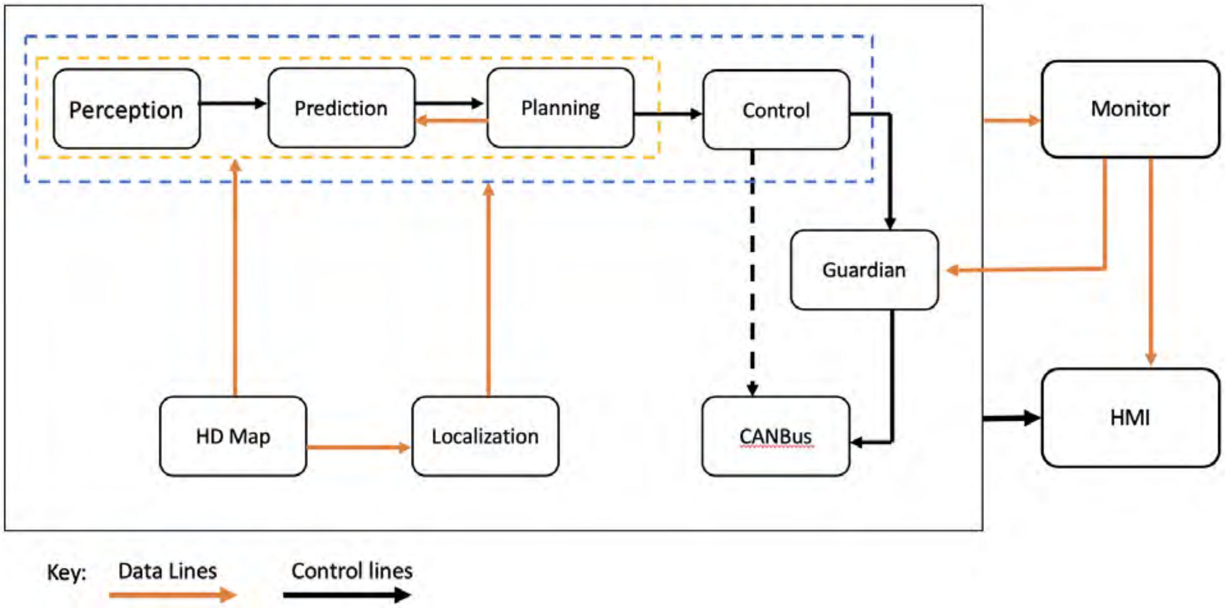

Figure 2. Software stack diagram of Apollo and the different sub-systems.

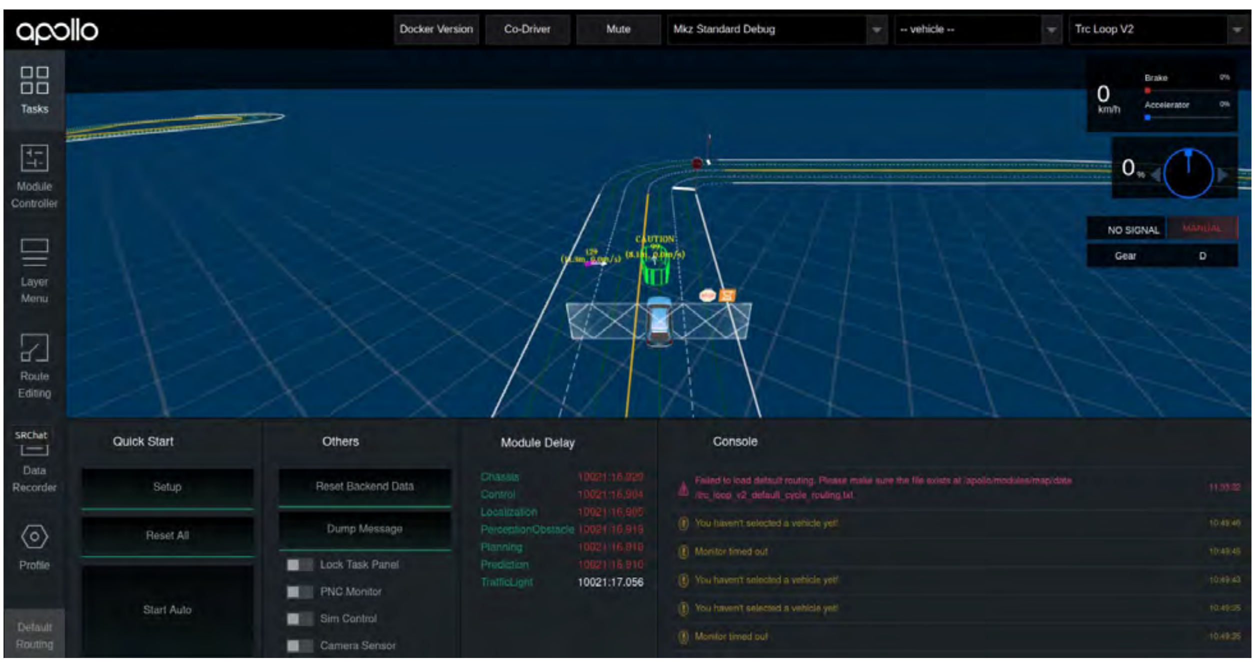

Figure 3. View of Apollo's Dreamview visualizer with obstacle detection

The vehicle is equipped with numerous sensors that are required by Apollo such as LIDAR, GNSS/INS sensor, and cameras. Table 4 below shows important characteristics of the equipment installed in the ADS. Figure 4 shows the architecture of the sensor suite installed on the vehicle.

Table 4: Summary of the hardware and software integrated into the ADS platform

Equipment	Specs
Computer	Spectra 2 Intel XEON E2278G 8th Gen 2.1/4.4GHz 8C | 12T, 80W TDP processor - 32GB DDR4-2666Mhz SODIMM (2X16GB) - (1) 256GB M.2 2280 Solid State Drive - Primary - (1) 1TB 2.5" SATA III Solid State Drive - (2) NVIDIA QuadroRTX-A4000 GPU - Dual RTX-A4000
Radar	Continental (ARS-408-21) Long Range Radar Sensor 77 GHz Premium
Lidars	1. Velodyne (VLP-32C-A) (front center) 2. Velodyne (VLP-16-A) (left) 3. Velodyne (VLP-16-A) (right) 4. Velodyne (VLP-16-A) (rear)
GPS	NovAtel (NVL-KIT-LEVEL-2.5-OEM7-U) Includes: - 1x PwrPak7D-E2 dual antenna GNSS/INS enclosure containing OEM7720 with Epson G370N IMU. - GPS+GLO, L1/L2, - NovAtel CORRECT RT2+PPP+Single Point+DGPS PNT, - ALIGN Relative Positioning, - ALIGN Heading, - 20 Hz Data Output Rate, Raw Measurements, Interference Mitigation, SPAN + Land Profile, - Relative INS. - 2x Low profile, roof mount, dual-frequency GNSS antenna, L-Band, TNC female connector
V2X	Cohda Mk5 OBU - Not used for data collection or control
Control	AutonomoStuff Speed and Steering Control
Cameras	1. Leopard Imaging Inc. (LEP-LI-USB30-AR023ZWDR-6): 1080p WDR USB 3.0 Camera, Active pixel: 1928H x 1088V, Frame rate: 30fps, Pixel size: 3x3um, 6mm lens 2. Leopard Imaging Inc. (LI-USB30-AR023ZWDRB-12) USB 3.0, 12mm lens
RTK corrections	Cradlepoint: CPI-DOME-AN dome antenna, IBR-900 Router

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Equipment	Specs
Perception Stack	Apollo V5 • Localization module realized using GNSS with RTK • Primary perception module via lidar based object detection • Tracking and prediction module • Dynamic path planning module • Routing module plans the driving route which feeds the planning module. • Control module which defines velocity and angle of vehicle. • Live traffic operation using GNSS based localization on an AS approved route. • AutonomouStuff basic localization
Drive by wire	Hexagon PACMod Throttle & brake by-wire controller module, steering & shifting by-wire controller module

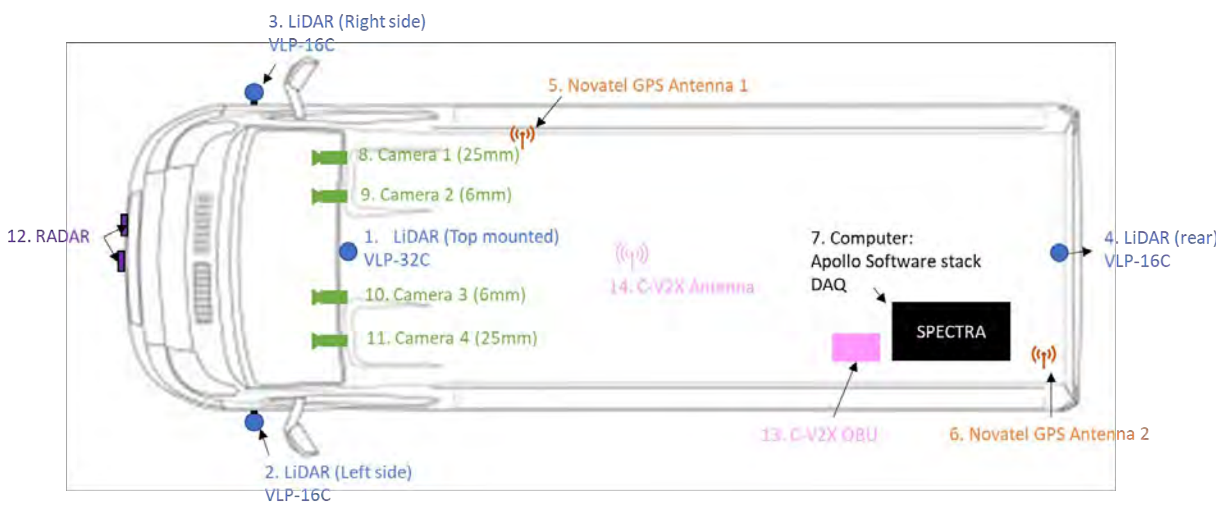

Figure 4: Schematic diagram of the sensor suite on the Ford Transit van

1.5 HD Maps

All the three ADS platforms evaluated for project, CARMA, Autoware, and Apollo, use High Definition (HD) lane vector maps for navigation. HD maps contain information about the road network with centimeter level accuracy. These maps include precise locations of the lane lines, stop-bar locations for stop signs and stop-lights, traffic-light locations on the map, speed limits, and all possible turns on intersections. The automation stack uses GNSS to locate the vehicle's position in reference to the lane lines in these maps. The error from desired position is used to navigate the vehicle. Hence these maps are an integral part of the ADS functionality, and accuracy and correctness of these maps have great influence on the operation.

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In this project, the team received HD maps from Mandli Communications in a form that can be loaded in these systems. During the trial phase of Carma, only maps for TRC's SMARTCenter were prepared. For Autoware testing and deployment, TRC's SMARTCenter and the chosen routes in Central Ohio were prepared. Finally, for Apollo testing and deployment, several routes in south-east OH and TRC's SMARTCenter were prepared. In the following sections, we describe the general process of procuring, validating, and correcting these maps.

1.5.1 HD Maps for Phase-1 Deployment

The objective of deployment is to gather data needed to develop an understanding of the challenges in developing and operating an ADS in rural environments. The route choices were made specifically to represent the rural environment characteristics. Total five routes were selected. Routes had a maximum speed limit of 50 mph, unprotected right turns, traffic light intersections, four ways stop, two way stops, and unprotected rail crossing.

Map Validation: As mentioned in the map section, the HD maps, also called vector maps, are the basis for the planning module for ADS operation. The map format for Autoware is *lanelet2* vector maps developed by Mandli. The map data was collected and processed, before loading onto the vehicle's computer. The validation for the maps was done in multiple steps.

1. The lanelet2 maps were viewed in an open-source software, **JOSM**, for initial validation by manual comparison with maps of the roads along the entire route.
2. Next, the map is loaded into the Autoware stack, and a route was simulated. The simulation was done with the predetermined path (start and end goals). The purpose of simulation run was to verify that the planning algorithm is properly consuming the map data. All the speed limits, stop lines, and intersections are designed properly and there is no discontinuity in the lanelet vectors.
3. Then the route is manually driven with the vehicle either collecting sensor data or with the software running, but not engaged in driving the vehicle, called manual and shadow mode, respectively. The safety engineer is responsible for monitoring the position of the car is correct after localization in rVIZ (Autoware HMI visualizer)
4. Finally, the full ADS mode was used and any discrepancies were reported to the Mandi team to get subsequent correction in the map versions.

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1.5.2 Routes for Deployment

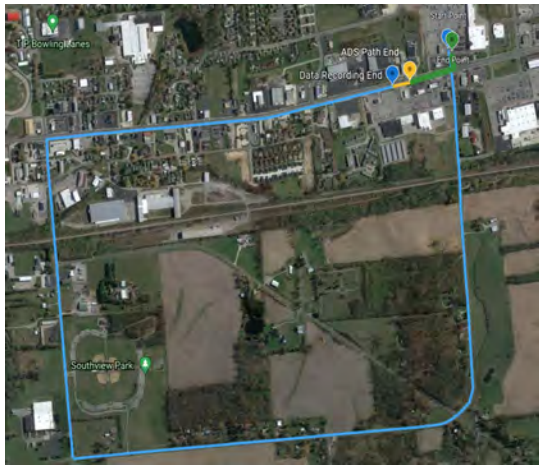

Figure 5: Bellefontaine - Travel Direction Clockwise

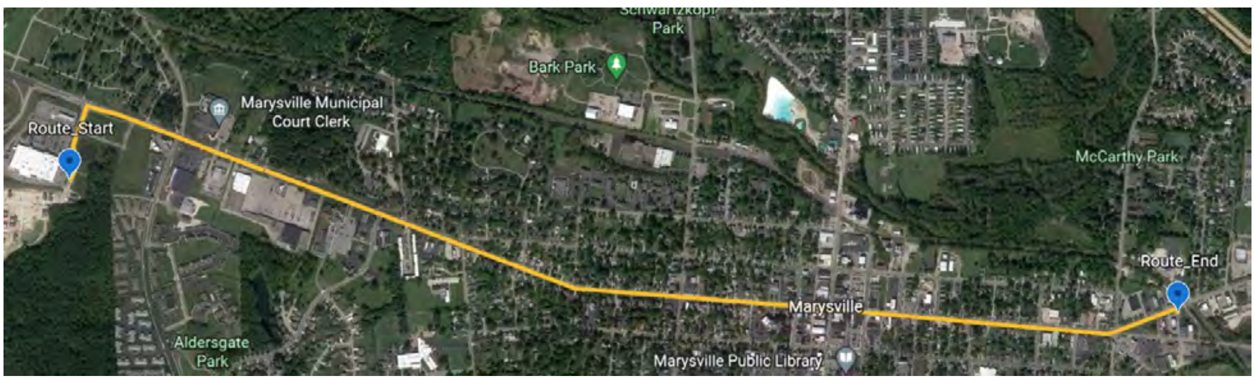

Figure 6: Marysville

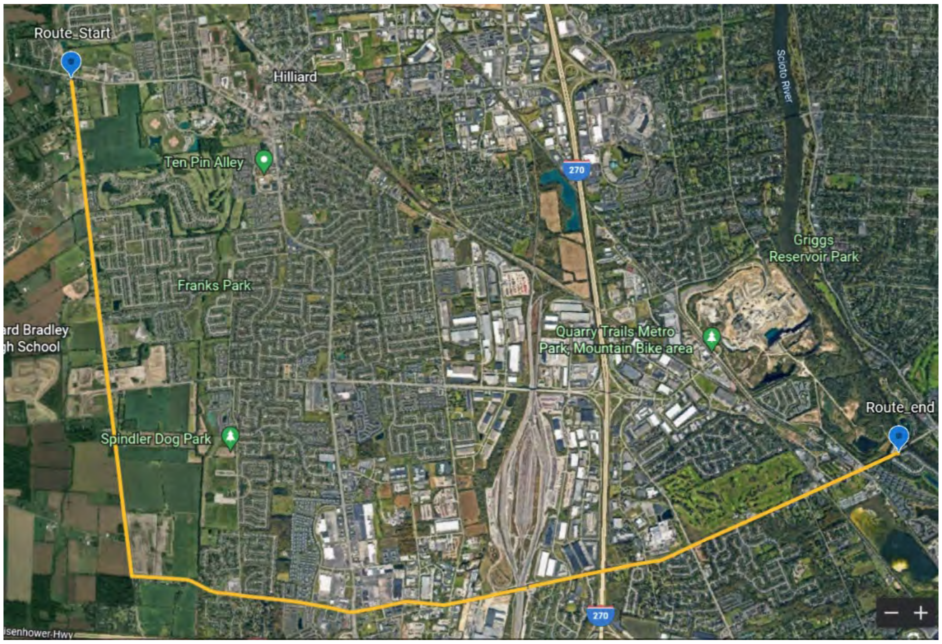

Figure 7: Renner

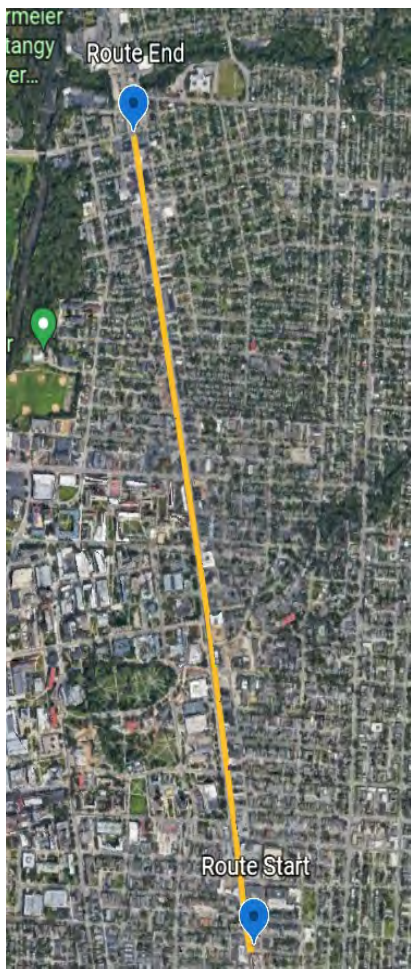

Figure 8: North High

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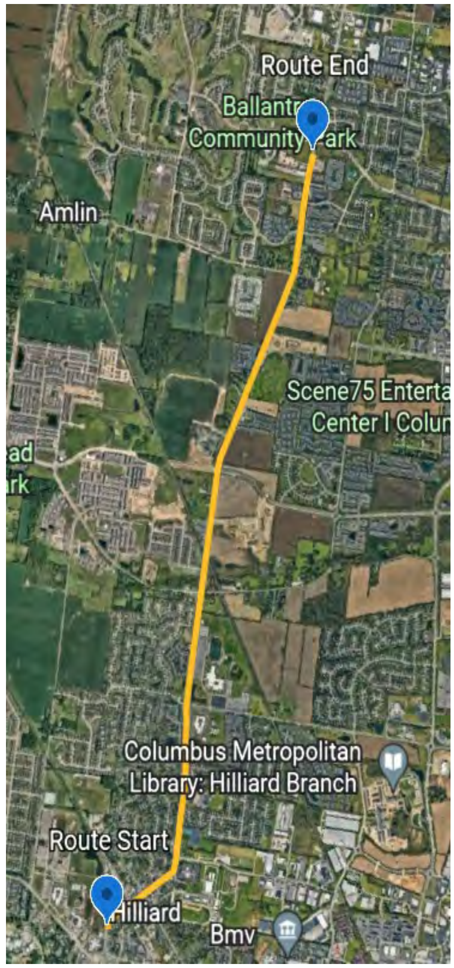

Figure 9: Avery Rd

Table 5: Route Parameters

S No.	Route Name	Length (Miles)
1	Bellefontaine	3.3
2	Marysville	2.5
3	Renner	8.8
4	North High	1.9
5	Avery Rd	3.8

1.5.3 HD Maps for Phase-2 Deployment

For deployment Phase-2 Apollo compatible maps were procured from Mandli for TRC SMARTCenter and the three chosen routes in southeast OH.

Map Verification: For all the routes, maps were verified to ensure their correctness for lane line positions in global coordinates, speed limits, and stop-bar locations. Apollo's Dreamview shows a live view of vehicle position and speed limits while driving on the route. For safety purposes, we adopted a two-step approach for map validation. In the first step, we drove the vehicle in shadow mode along the route while manually keeping the vehicle centered in the lane. During this driving, an ADS operator monitored the Dreamview interface taking notes of inconsistencies in the map including speed limits, lane line departures, and traffic light or stop sign detections. Localization data was also recorded during this drive. Plotting the localization data during manual driving on the HD maps and close examination of these plots revealed inconsistencies between actual and map speed limits or lane locations. An example of red route speed limit suggestions is shown in Figure 10. Some basic map errors were also identified during the manual drive; for example, a stop sign intersection was incorrectly marked as a signalized intersection. Similarly, a railway crossing was marked as railway crossing in the map although the ADS platforms were incapable of navigating around railway crossings. Hence, it was changed to a stop sign intersection for better operation and to give time to the drivers to disengage if railway crossing gate is down.

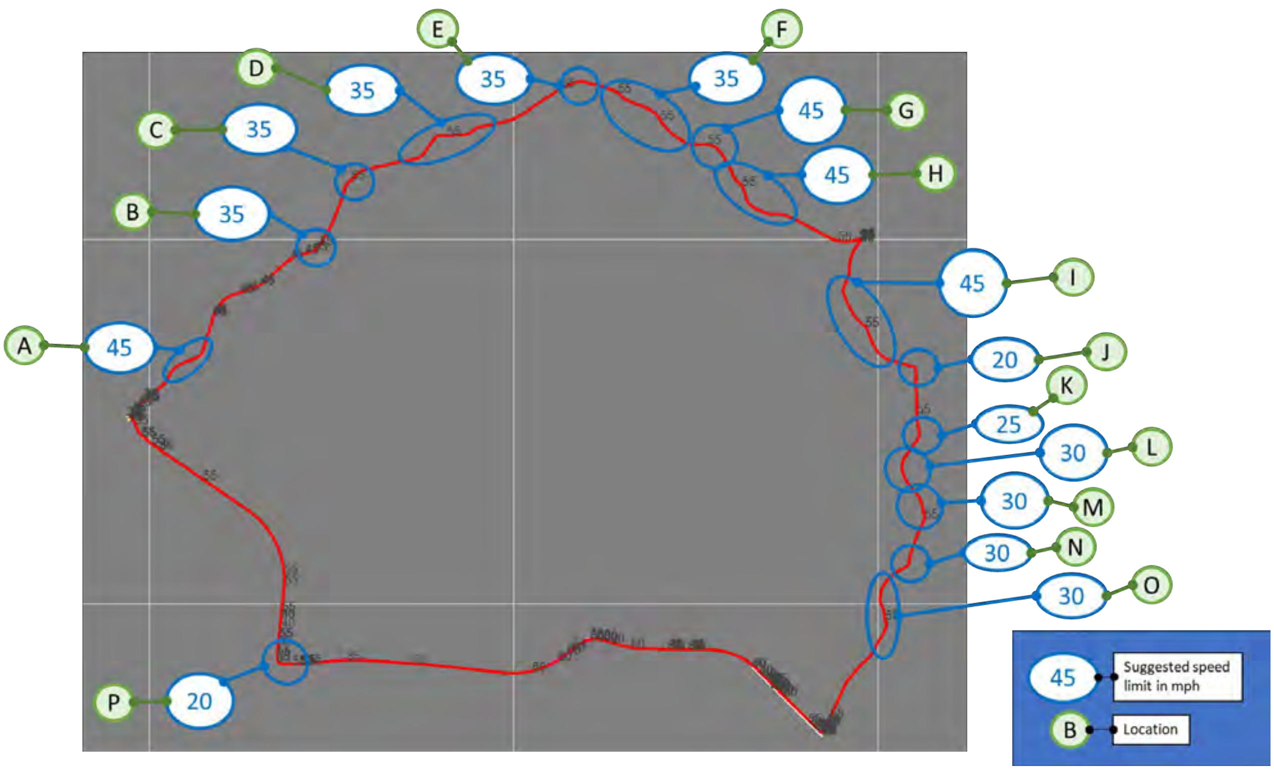

Figure 10: Red route speed limit discrepancies.

When the speed limits, lane locations, intersection types were verified and corrected by manual driving, the system was engaged in autonomous mode on these routes. The main goal of this map verification phase was to identify places on the route where the system is not able to operate properly. For example, on a small segment on the Green route, due to a steep up-hill road and multiple connecting driveways and visibility issues, the speed limit was reduced from

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55mph to 45mph for safety purposes. Furthermore, at some intersections, we noticed that the automation system failed to turn on the turn signal. This was because the map did not have splitting road segments at those intersections.

Table 6 below shows the updates made to the HD maps for the TRC vans.

Table 6: Map version updates

Route	Map Version	Date	updates
Blue	V2F	June 13, 2023	Update speed limits to the actual road limits and suggested speed limits near the turns
Blue	V3	September 6, 2023	Update speed limits to the actual road limits and suggested speed limits near the turns; update the discontinuity in the map.
Red	V3	June 30, 2023	Update speed limits to the actual road limits and suggested speed limits near the turns
Red	V4	September 6, 2023	Update speed limits to the actual road limits and suggested speed limits near the turns
Green	V3	June 30, 2023	Update speed limits to the actual road limits and suggested speed limits near the turns; update lanes near turns to capture the actual travel path
Green	V4.35	September 6, 2023	Update the maximum speed limit of all the roads except the state route to 35mph
Green	V4.45	September 6, 2023	Update the maximum speed limit of all the roads except the state route to 45mph

1.5.4 SE Ohio Maps for Autoware (UCLA)

Autoware.ai, being at the forefront of open-source autonomous driving software, necessitates an accurate depiction of the environment to ensure the safety and reliability of its navigation capabilities. High-definition (HD) maps, such as lanelet2 vector maps, are crucial for the functionality of Autoware.ai in autonomous driving systems due to their accuracy and detail in road network representation. To be more specific, the comprehensive data within lanelet2 maps facilitates robust path planning. These maps contain exhaustive information about lane configurations, traffic direction, junctions, and road attributes. Such detailed knowledge allows Autoware.ai to compute proper paths.

The generation of HD maps, specifically the lanelet2 vector maps for Autoware.ai, follows a comprehensive process that begins with the collection of multi-modal sensor data. This data is primarily sourced from GPS, Inertial Measurement Units (IMU), cameras, and LiDAR systems. Each of these sensors plays a pivotal role in capturing different aspects of the environment. For instance, GPS provides global localization, IMUs offer vehicle dynamics and orientation, cameras capture visual features, and LiDAR sensors generate detailed three-dimensional point clouds of the surroundings.

Figure 11 shows the pipeline of the HD map generation process. The first step in the HD map creation pipeline is the calibration of these multi-modal sensors. Calibration is crucial as it aligns and synchronizes data from different sources, ensuring accuracy in the representation of the vehicle's surroundings. Following calibration, feature extraction takes place. During this phase, specific characteristics such as lane markings and traffic signs are identified and extracted from the sensor data. Once features are extracted, data association is performed. This involves linking the extracted features with corresponding 3D elements within the point cloud map data. The point cloud map is a high-resolution 3D representation of the environment constructed from the LiDAR data. This map is useful for providing 3D information in three dimensions. The final stage of the pipeline is the actual generation of the lanelet2 map. This process takes into account all the associated data and the detailed point cloud map to create a vector map that accurately represents the drivable lanes and their relations.

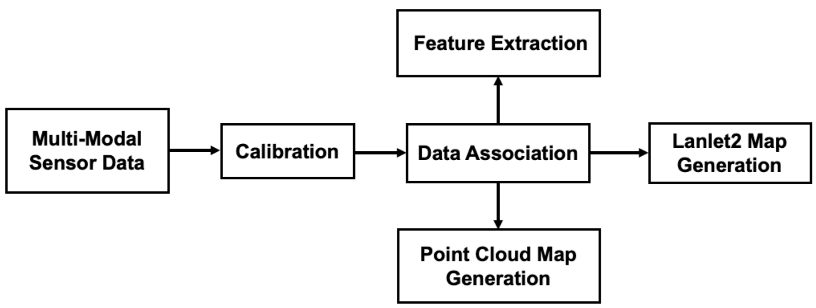

Figure 11 HD Map Generation

2 Controlled Environment (CE) Testing

The Controlled Environment Testing took a phased and categorical approach towards developing an understanding of the ADS-equipped vehicle’s capabilities to operate safely on public roads. The scheme was structured to expose the ADS-equipped vehicle to progressively complex situations, test the ADS’s response, and inform the safety operator of expected system behavior.

2.1 CE testing for Phase 1 Deployments

A detailed CE test report for phase 1 had been submitted to CDM Smith (Appendix B3). Please refer to that document for details. In this report only a high-level summary will be presented.

An ADS stack is a combination of various modules and hardware sensor with actuators. The ADS used in phase1 Autoware was an open source forked version developed by Autonomous Stuff

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with certain ODD requirements. The sensor suite was not state of art thus limiting the range of detection and speed limitations. The base of Autoware was also ROS1 which had latency issues in edge cases detection. The table below shows the high-level test and their observations.

Table 7: Summary of Findings from CE Testing Phase 1

Issue	ODD	Solution (Disengagement conditions)
Object detection distance is ~40m	Vehicle Speed: >35mph Other object: Slow/stopped in the same lane	When the vehicle fails to slow down at a comfortable rate, disengage or drive manually.
High lateral error while engaging in a curve	Vehicle speed: >5mph Event: Engaging ADS into auto in a curve	Only engage the ADS when steering wheel is aligned to center. (approx. 0 degree steering angle)
Traffic light detection uncertainty	Location: Approaching or stopped at signalized Intersection	Missing the traffic light location. One solution was to increase the segmentation bounding box. Other precaution is to disengage if wrong location of bounding box or state
Able to engage with corrupt state of Lidar or other primary sensors	Applicable for any ODD conditions	Check for lidar point cloud frequently real time using a script. Disengage and warn SD if messages drop.
Misclassification of other agents	Intersections and oncoming traffic. VRU at crossings	The lidar based classification was not robust. For any VRU in vicinity the ADS was disengaged.
Prediction of intent of agents	Applicable for intersection. Four way stops. Right and left turns	No proper module for prediction intent of agents. Thus at four way stops and right turns pre-determined disengagements were planned.

2.2 CE testing for Phase 2 Deployments

Safety of the drivers, other road users and the vehicles was of paramount importance in this project. Before deploying the vehicles on public roads we performed extensive testing on closed course at TRC Inc. proving grounds to ensure the system meets the desired capabilities. Detailed test plan, results, data analysis and conclusions are documented in CE test report (Appendix B5) and an SAE World Congress 2024 paper (Appendix B7). Hence, only summary of the CE testing is presented in this report.

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2.2.1 ODD and ADS Platform Capabilities

Although the system is theoretically capable of performing all L3 tasks, the goal was to always have a 'trained' and expert driver behind the wheels to take control. The expectation from the expert driver was to prevent the vehicle from entering safety critical situations or take control if critical situations occur. Similarly, the driver was expected to take control under unexpected scenarios and edge cases. Hence, the ADS platform was only tested for commonly encountered, non-safety-critical scenarios.

The routes are chosen so-as-to encompass typical north American rural driving environments. The choice of these routes defined the ODD for SV's deployment. The ODD includes suburban roads, highway, main arterial roadways, rural roads with low traffic and hilly curvy roads. These routes include different types of intersections e.g. roundabout, stop-sign and signalized. The rural environment is expected to have wide variety of road users including sedan cars, trucks, freight trucks, tractors, adult pedestrians, child pedestrians, and animals like deer.

The Apollo based ADS platform is not capable of handling the vehicle under low road-surface friction conditions. Hence, the vehicles were not expected to operate under snow, heavy rain and high wind conditions.

2.2.2 Test Plan

A test plan consisting of safety maneuver tests (e.g. NHTSA PAEB tests) and system performance tests was developed. The test plan included 4 test sets: 1) General driving, 2) Obstacle avoidance, 3) Car following and 4) Intersection safety. Each test under this test plan was repeated at least 3 times. Some system upgrades were made during CE testing phase as well as during deployment. Relevant subsets of these tests were repeated after each upgrade.

The main goal for general driving tests were to evaluate if the system is capable of following prescribed path, recognize and stop at stop sign and traffic signal, engage into autonomous mode when driving at speed, and perform lane changes. All these tests were conducted with no other road users around the subject vehicle.

After validating the basic driving capability of the ADS platform, the team tested its obstacle detection and avoidance capabilities. TRC Inc. has different types of strikable surrogate targets including soft car, adult pedestrian, child pedestrian, bicyclist, motorcyclist and deer. All these targets were used on the test track to compute detection accuracy and to test if the ADS platform is capable of applying brakes and avoid collision. The object detection capability was tested on straight and curved road geometries. Further, the vehicles ability to navigate around moving objects was tested. TRC Inc. has robotic platforms that can act as secondary objects on the road. Various scenarios were simulated with these platforms in the loop. The scenarios included – car following, cut in, suddenly revealed stopped obstacle and secondary vehicle in blind spot.

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Finally, systems capability of navigating at intersections with other road users present was tested. Intersection safety was assessed at different conflict points typically encountered on the chosen routes. Driving scenarios were designed based on these conflict points. More specifically, scenarios for unprotected left turns, turn only lanes, yield for oncoming traffic and yield for pedestrians at stop signs were considered.

2.2.3 Summary of Findings and Recommendataions

Object Detection:

During CE testing, it was noticed that the Apollo system was not able to avoid stopped obstacles when driving above 35mph. This led to further investigation into the system's object detection capabilities. Tests with different target objects, distance and speed were conducted by the TRC team at TRC SMARTCenter. At the end of these tests, it was concluded that the Apollo system has object detection range of approximately 50m for standard sized cars and adult pedestrians. The detection distance is ~25m for large objects like truck trailers and small objects like child pedestrians. The Hexagon team and Iowa team have experienced similar object detection distances with identically configured systems. Assuming 50m object detection distance, the vehicle will not be able to come to a complete stop from speeds above approximately 35mph. Hence, the recommendation is to drive manually if a stopped obstacle is present in the driving lane while driving at the speed above 35 mph.

Traffic Light Detection:

The TRC team observed that Apollo traffic light detection system is not reliable. The uncertainty in the detection could be due to calibration of the camera, the detection algorithms, position/orientation of the vehicle, etc. During the initial system assessment and learning phase, the detection algorithm was calibrated multiple times, and it was concluded that the uncertainties could not be resolved. Hence, a dashboard indicator light was designed and implemented to show the traffic light color the Apollo is perceiving. This way if there is a discrepancy between the Apollo's perceived traffic light color and the actual traffic light color, the driver can disengage and drive manually.

Lane Keeping on Curved Roads:

The TRC team experienced uncomfortable driving on curved sections. The system was able to keep the vehicle inside the lane line markings, but it did not slow down enough to ensure comfortable lateral acceleration and lateral errors. The driver and the operator "felt like the vehicle was going to leave the road and would have slowed down if manually driving." It is therefore advised to disengage on the curved road if the system does not slow down to a comfortable speed.

Lane Change in Presence of other vehicles (POV) in Blind Spot:

The TRC team ran tests where a platform with SoftCar was in the blind spot when the system's objective was to make a lane change. This scenario is shown in Figure 12. It was observed that the system went too close to the POV. This is possibly due to conflicting decisions between obstacle avoidance and planned route. In a very unlikely scenario where the POV stays in the adjacent lane while the system is attempting lane change, the vehicle may start drifting towards the POV. Hence, when the system attempts to make a lane change and there is another vehicle nearby in the adjacent lane, it is recommended to disengage and drive manually.

Figure 12: Lane change scenario with POV in blind spot

Sudden large steering torque when engaging at speed:

A controlled environment test was conducted to assess the ability of the system to engage or re-engage into autonomous mode when manually driving at higher speeds. In this test a routing request requiring lane change was sent. The vehicle was driven manually for some distance in the same lane and then, while driving, the system was engaged into autonomous mode. It was observed that the system replanned to route and made a sudden lane change with unacceptable steering rate. To avoid this situation, it is recommended not to engage the vehicle in autonomous mode while driving at higher speed when the planned route has an upcoming lane change on the same road segment.

Table 8: Summary of Findings from CE Testing

Issue	ODD	Solution (Disengagement conditions)
Object detection distance is ~50m	Van Speed: >35mph Other object: Slow/stopped in the same lane	When the vehicle fails to slow down at a comfortable rate, disengage or drive manually.
High steering rate when engaging at high speed	Van speed: >5mph Event: Engage at speed when there is lateral error	Do not re-engage when driving at speed and when the vehicle is not at the (approximate) center of the desired lane
Traffic light detection uncertainty	Location: Approaching or stopped at signalized Intersection	Check traffic light indicator to ensure the Apollo stack perception is detecting correct traffic signal. In presence of discrepancy, drive manually.

Issue	ODD	Solution (Disengagement conditions)
Detection distance is ~25m for small objects	Van speed:>25mph Other object: Slow or stopped in the same lane	If the vehicle fails to start slowing down in presence of obstacles, disengage and do not wait for the vehicle to react.
Fails to detect large objects (trucks and busses)	Other object: Bus, truck-trailer	Keep safe distance from large objects. If vehicle is unable to keep safe distance, disengage and drive manually
In-accurate lane keeping on curved roads	Van speed:>25mph Road: Curved	If vehicle fails to slow down for curved roads, or fails to stay in the lane, take over and drive manually
Does not allow other vehicle to pass when immediate Lane change is required	Other object in blind spot Immediate Lane change required	If vehicle starts drifting towards adjacent lane when there is vehicle in blind spot, disengage and drive manually. Make a lane change safely and then re-engage.
Apollo trying to do a hard stop on the road.	Van Speed > road speed limit or the max speed limit set for the road in the maps.	Do not engage Apollo when the Van speed is higher than the road speed limit; bring the van closer to the road speed limit and engage Apollo.

The recommended solutions are purposefully kept subjective to driver's perception of safety as objective measurements of safety metric are not feasible. The recommendation is to disengage when driver feels unsafe.

2.2.4 Additional Tests: Bad Weather Data Collection

The TRC team conducted 3 CE tests at TRC Inc's SmartCenter during a snow-storm to understand how the object detection capabilities were hampered by the snow. The three tests included stationary obstacle (a sedan) and moving obstacles. The tests were conducted at slow speeds (<45mph) in manual mode for safety reasons.

It was observed that the object detection module was tricked by the cloud of snow from the front vehicle into detecting objects that did not exist. An example is shown in Figure 13.

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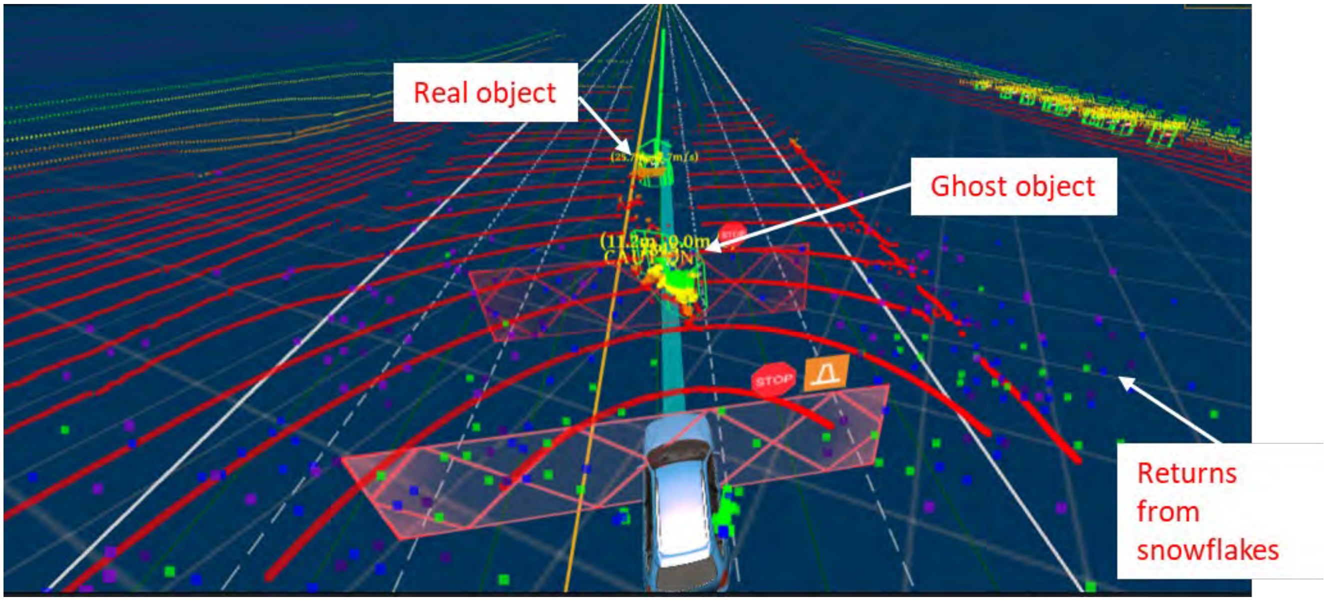

Figure 13: Observation from tests under snowy conditions. The object detection algorithm was tricked by the snow cloud to detect objects that didn't exist in reality.

Figure 14: Actual image of the object from the camera during snow test. This image corresponds to the LiDAR data shown in Figure 13.

More data analysis is required to quantify the effect of snow on object detection capabilities.

3 Phase 1 Deployment

3.1 Planning

After the conclusion of CE testing the deployment for phase 1 was done on the 5 routes. Route details are mentioned in section 1.5.1. During the CE testing issues were identified with control and perception. Hence for safety reasons, it was decided by the team to divide the data collection intro three modes. These three modes are explained below:

1. Bucket 1**: Completely manual mode**. The main goal here is to generate data from the vehicle about its own location and actors around the vehicle. In this mode of operation, the safety driver has full control of the vehicle and automation is turned off. However, the localization and perception modules are launched in the software. Which means data from all the sensors, perception algorithms and localization is available and logged if the vehicle is on the routes.
2. Bucket 2: **Shadow mode with safety driver in full control.** This mode of operation differs from manual driving because here the ADS stack is provided with a destination as shown in rviz window in Figure 15. When destination point is available, the ADS software plans a route. The vehicle was not engaged into auto mode and safety driver was responsible for the full control of the vehicle. The benefit of this mode was to collect the motion control and planning algorithms outputs. Hence, in this mode the data from the planning and control module is also available besides the data collected in manual mode. The only concern was safety driver cannot deviate a lot from the planned path (lanes); otherwise the mode will disengage itself within a buffer zone and will stop publishing results from the motion control algorithms.
3. Bucket 3: **Full autonomous mode with ability to disengage by safety driver.** In this mode the ADS is fully engaged, and safety driver was instructed to take over in the case of safety critical situations. In this mode the control module of the ADS is controlling the steering, brake and gas pedals using the Drive-by-wire module.

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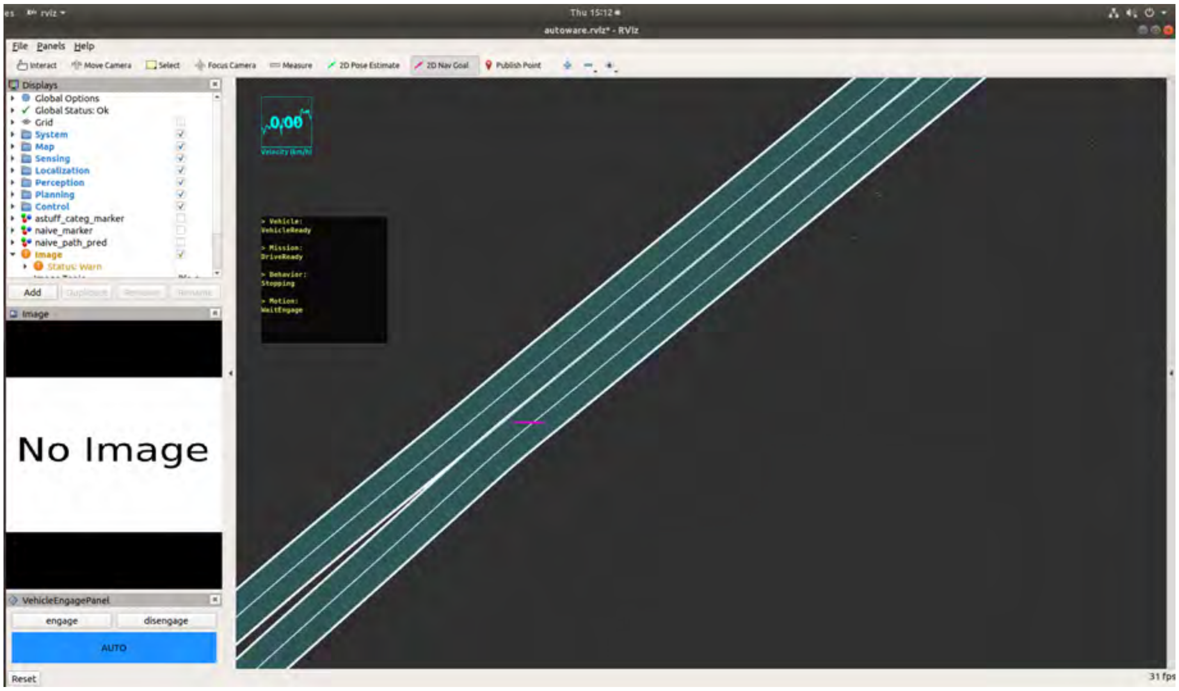

Figure 15: Autoware rViz visualizer used for selecting the destination point.

3.1.1 State Of Practice

In the deployment plan submitted to Drive Ohio for phase 1, it was decided to increase the bucket 3 collection if the safety driver and operator find the ADS operation safe enough after bucket 1 and bucket 2 data collection. During any anomaly on the route, e.g construction zone, emergency vehicles etc., the safety driver was instructed to disengage the ADS and re-engage only after clearing the anomaly.

Before the deployment, two safety drivers were trained during the CE testing. Drivers were made acquainted with how the ADS is engaged and what to expect from the control behavior in various closed course scenarios.

3.1.2 Deployment plan

Deployment was in five routes. The deployment was preceded by driver training in closed course for one week for two drivers.

Deployment Timeline:

S No.	Task/Milestone	Schedule
1	Driver Training	31st March - 7th April
2	Bellefontaine	11th April – 18th April
3	Marysville	20th April – 27th April
4	Avery	29th April – 6th May
5	High Street	9th May – 16th May

For more details regarding the deployment timeline, please refer the deployment plan for phase 1 (Appendix B4).

Table 9: Estimate of deployment for each bucket

Data Collection Mode	Estimated # of Runs	Estimated Miles
Bucket 1	202	796
Bucket 2	101	398
Bucket 3	15	60
Total	**318**	**1254**

3.1.3 Pre-deployment

Before the deployment the safety driver (SD) and test engineer (TE) have to complete the checklist mentioned below:

- Weather conditions for deployment day (Responsibility: SD). Checking the weather conditions was important considering no weather treatment and sensor cleaning options available on the external sensors. The object detection by lidar gets affected by snow accumulation or extreme humidity and rain. For validation one of the day sensor data was collected in bucket mode 1 to check degraded object detection by Autoware.
- Construction zones in the deployment route (Responsibility: TE). Check if the construction zones affect the global route created by Autoware in real time. Inform the SD for any pre-determined dis-engagement because ADS couldn't handle construction zones.
- Before start of deployment, launch the autonomy and platform (sensor stacks) at TRC Inc. (Responsibility: TE), check the lidar point cloud and the camera output in ROS nodes and rviz for consistency and then reboot the stack if any errors (message dropping etc.) were observed.
- Check the external sensors mount and hardware for any physical damage (Responsibility: SD).
- Check the fuel and refill the before leaving for deployment (Responsibility: SD).

3.1.4 Post-deployment

During post deployment the data upload and integrity checks happened, and any safety concerns were communicated to project team. The Figure 16 shows how the data uploaded from the Autoware compute to cloud. The team at TRC developed a script for automating and checking the upload of raw rosbags. A script was also developed to convert the raw rosbags topics into mongo DB database for internal data analysis.

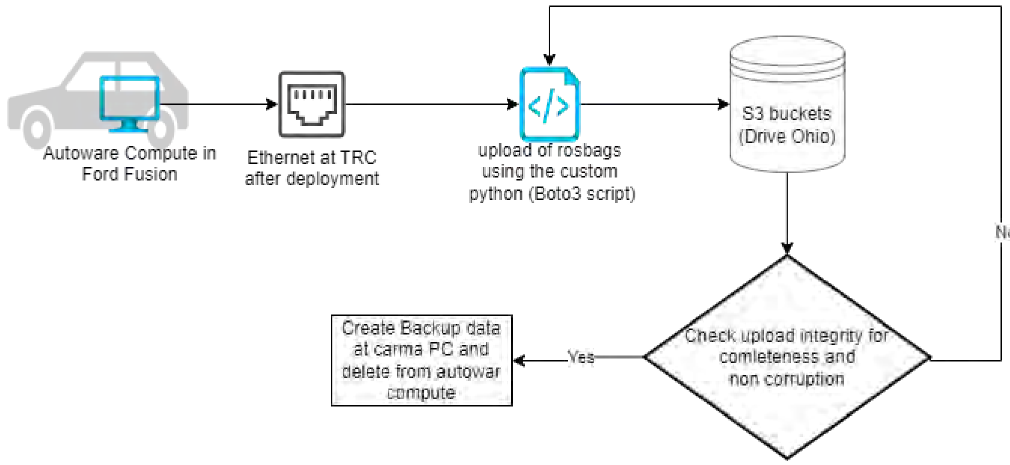

Figure 16: Data Management Flow Chart

3.2 Data Management

3.2.1 Vehicle Data

The ADS in phase 1 Autoware is based on ROS1. Each module of ADS stack publishes data in formats of ros messages using ros nodes. Each ros node has publishers and subscribers parts in the node. For each bucket type specific channels are stored in rosbags with their message names. More details regarding each message can be found out using Autoware github page. The tables below show which messages were present for each bucket. The common messages in the subsequent buckets are not repeated and only exclusive messages are mentioned.

Table 10: List of Message Names in Autoware Bucket 1

Message Name		
/am/bsm_self_hex	/detection/shape_estimation/objects_markers	/ssc/brake_command_echo
/astuff_btn	/detection/unbounded_objects	/ssc/brake_feedback
/cam/usb/compressed	/diagnostics	/ssc/cabin_report
/camera_fl/image_raw/compressed	/gps/fix	/ssc/curvature_feedback
/can_bus_dbw/can_rx	/gps/gps	/ssc/gear_command_echo
/can_bus_dbw/can_tx	/gps/imu	/ssc/gear_feedback
/ctrl_cmd	/lidar_nodelet_manager/bond	/ssc/gear_select
/ctrl_raw	/light_color	/ssc/hill_start_assist
/current_pose	/linear_velocity_viz	/ssc/menus_input
/current_velocity	/node_status	/ssc/module_states
/decision_maker/available_transition	/novatel/oem7/bestpos	/ssc/speed_pedals
/decision_maker/state	/novatel/oem7/bestutm	/ssc/steering_command_echo
/decision_maker/state_msg	/novatel/oem7/bestvel	/ssc/steering_feedback
/decision_maker/state_overlay	/novatel/oem7/corrimu	/ssc/steering_wheel
/detection/lidar_detector/objects_markers	/novatel/oem7/driver/bond	/ssc/throttle_command_echo

Message Name		
/detection/lidar_detector/points_cluster	/novatel/oem7/heading2	/ssc/throttle_feedback
/detection/lidar_objects	/ssc/turn_signal_command	/vehicle/misc_1_report
/novatel/oem7/inspva	/ssc/velocity_accel_cov	/vehicle/odom
/novatel/oem7/inspvax	/tf	/vehicle/sonar_cloud
/novatel/oem7/insstdev	/tf_static	/vehicle/steering_cmd
/novatel/oem7/oem7raw	/tracking/objects	/vehicle/steering_report
/novatel/oem7/time	/tracking/objects_markers	/vehicle/surround_report
/points_raw	/vehicle/brake_cmd	/vehicle/throttle_cmd
/prediction/objects	/vehicle/brake_info_report	/vehicle/throttle_info_report
/prediction/objects_markers	/vehicle/brake_report	/vehicle/throttle_report
/prediction/path_markers	/vehicle/disable	/vehicle/tire_pressure_report
/roi_signal	/vehicle/fuel_level_report	/vehicle/turn_signal_cmd
/rosout	/vehicle/gear_report	/vehicle/twist
/rosout_agg	/vehicle/gps/fix	/vehicle/wheel_position_report
/scan	/vehicle/gps/time	/vehicle/wheel_speed_report
/ssc/adas_input	/vehicle/gps/vel	/vehicle_cmd
/ssc/arbitrated_speed_commands	/vehicle/imu/data_raw	/vehicle_status
/ssc/arbitrated_steering_commands	/vehicle/joint_states	/velodyne_packets
/ssc/blind_spot_indicators		

Table 11: Additional Message Name in Bucket 2

Message Name	
/base_waypoints	/local_waypoints_mark
/based/lane_waypoints_array	/mpc_waypoints
/based/lane_waypoints_raw	/obstacle_waypoint
/change_flag	/red_waypoints_array
/closest_waypoint	/ref_traj_viz
/current_lane_id	/safety_waypoints
/detection_range	/state/stopline_wpidx
/final_waypoints	/stopline_waypoint
/global_waypoints_mark	/tlr_result
/green_waypoints_array	/tlr_roi_image
/lamp_cmd	/tlr_superimpose_image
/lane_select_marker	/traffic_waypoints_array
/lane_waypoints_array	/vehicle_location
/lanelet_map_bin	/vehicle/engage
/lanelet2_map_viz	/visible_traffic_lights_triangle
/lateral_tracking_error	

Table 12: Additional Message Names in Bucket 3

Message Name	
/am/bsm_hex	/ssc/arbitrated_speed_commands
/am/bsm_self_hex	/ssc/arbitrated_steering_commands
/audio/audio_info	/ssc/gear_command_echo
/can_bus_dbw/can_err	/ssc/gear_select
/car_auto_drive_state	/ssc/turn_signal_command
/decision_maker/stop_zone_visualizer	/vehicle/enable
/novatel/oem7/insconfig	/vehicle/gear_cmd
/novatel/oem7/rxstatus	/vehicle/turn_signal_cmd
/obstacle	

The data collected from deployment is stored in rosbag format. Autoware was set to record one single file for entire run, hence the individual file size depends on the total time of the run. After each day of deployment, rosbag files were uploaded to S3 buckets maintained on AWS servers which were allocated to TRC from DriveOhio. A backup copy of the files is kept at TRC Inc. on local hard drives. The backup was used for data analysis purpose by the TRC team. The total data collected was around **9.8 Tbs** in **277** total runs on 5 routes.

Data is stored as day wise deployments in backup and S3. The data also contains the text files and audio logs from safety operator in which the disengagement reasons are mentioned.

Figure 17 shows a particular day's data structure.

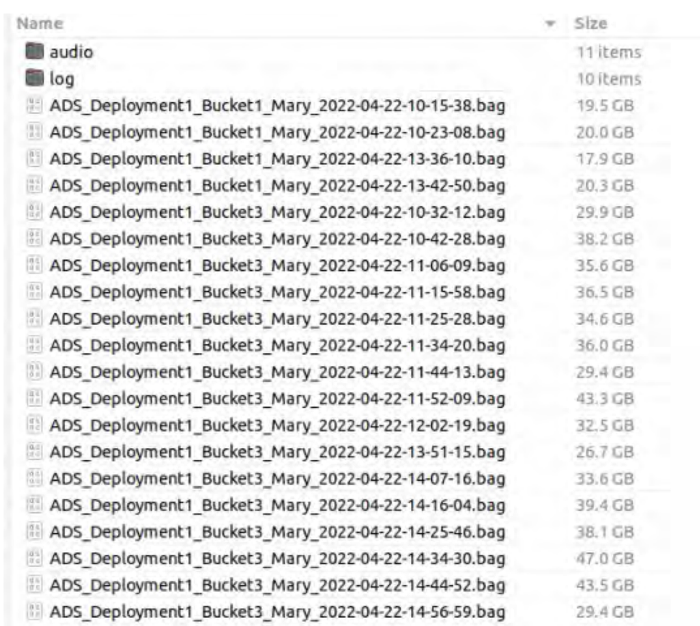

Figure 17: Deployment Data Structure

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3.2.2 Metadata and observation notes

No separate metadata file was created for the phase-1 deployments, instead the naming schema of the rosbag files was selected in such a manner that high level metadata like route, bucket type and date/time of the run can be easily extracted. The name schema was:

*"ADS_Deployment1_Bucket**Type_Route_yyyy-mm-dd-hh-mm-ss.**bag"*

The Figure 18 shows the structure of an audio recording directory. The method for audio recording will be explained in later sections. The name schema was:

*"ADS_Deployment1_Bucket**Type_Route_yyyy-mm-dd-hh-mm-ss_DisengagementNo.**mp3"*

Name	Size
ADS_Deployment1_Bucket3_Mary_2022-04-22-10-32-12_1.mp3	177.6 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-10-42-28_1.mp3	287.3 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-11-15-58_1.mp3	597.7 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-11-15-58_2.mp3	54.5 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-11-25-28_1.mp3	57.0 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-11-44-13_1.mp3	62.6 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-11-44-13_2.mp3	95.6 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-12-02-19_1.mp3	73.8 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-14-25-46_1.mp3	74.2 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-14-44-52_1.mp3	56.9 kB
ADS_Deployment1_Bucket3_Mary_2022-04-22-14-56-59_1.mp3	57.7 kB

Figure 18: Audio Recording for Disengagement File Schema

3.3 Data Analysis/Results

The Figure 19 shows the data volume in Gega Bytes (GBs). During the initial days of deployment, it was decided to prioritize the bucket 3 based on performance of ADS and confidence of the SD in disengaging the ADS in various edge cases. Based on initial feedback the bucket 3 data collection was improved a lot which is evident from data volume.

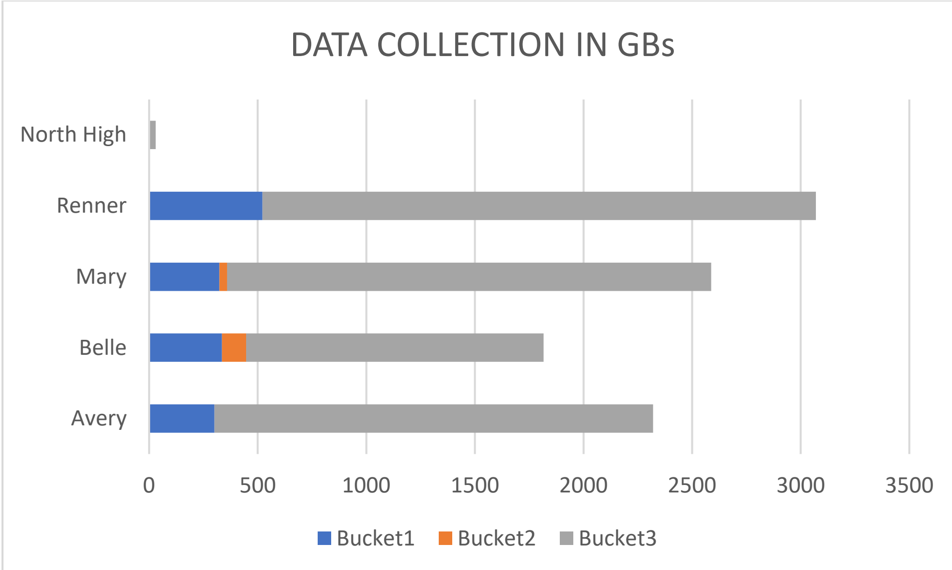

Figure 19: Route Wise Data Volume

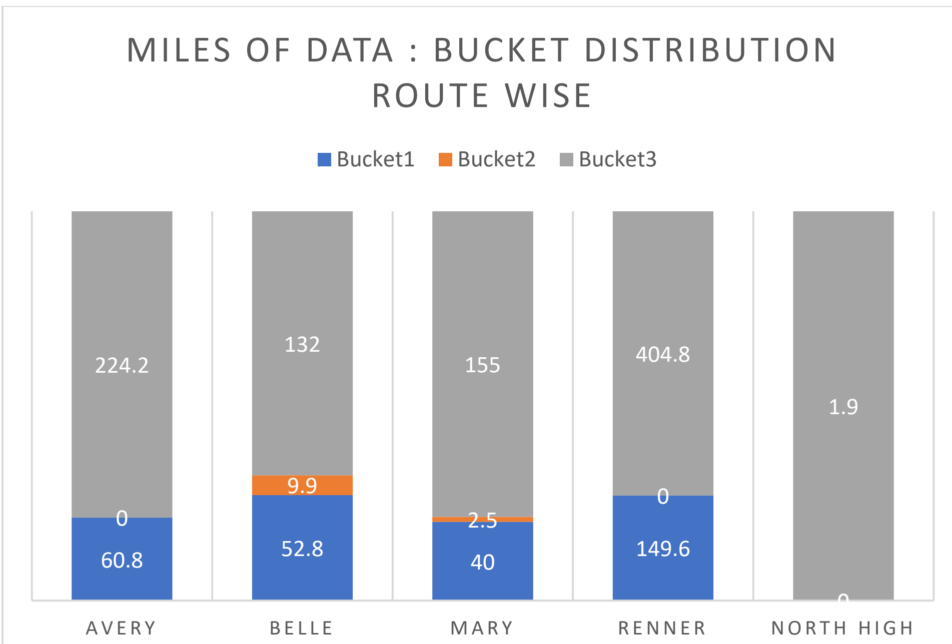

Figure 20: Route Wise Bucket Miles

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Table 13: Efficiency of Deployment

Data Collection Mode	Runs Collected	Miles	% Achievement of Miles (Collected Miles /Planned Miles) **
Bucket 1	65	303.2	38%
Bucket 2	4	12.4	3%
Bucket 3	208	917.9	1530%
Total	**277**	**1233.5**	**98%**

** The above calculation does not consider if disengagement happened or not i.e., the entire route distance is used as reference for calculation.

The team at TRC was able to achieve approximately 98% of the initial planned target data collection with a lot more data collected in bucket 3.

3.4 System Improvements

During CE testing and initial deployments a few shortcomings of Autoware software and hardware were discovered. In this section we describe improvements made by the TRC team.

3.4.1 Driver HMI button

After the destination point is selected in rviz window, and the route planner module successfully finds a route from current position to the destination point, the safety operator can engage the ADS. This method of engaging the ADS was not efficient for on road deployments as the test engineer had to communicate with safety driver before engaging. This introduced a need to have a separate button interface. The hardware button was by safety driver to engage the ADS. Figure 21 shows the button (hardware) used to engage into autonomous mode. A ROS node was developed by the TRC team which communicated with the Autoware stack to engage the ADS into autonomous mode after all other the necessary modules are ready from Autoware. The other issue we noticed during CE testing was that there was no clear visible indicator of current driving mode. Hence, the press button was chosen with color LEDs. Different illumination colors then indicated different driving modes. The switch color coding was as follows: Auto ready but not engaged– Green, Disengaged – Gray , ADS fully engaged (bucket 3) – Blue.

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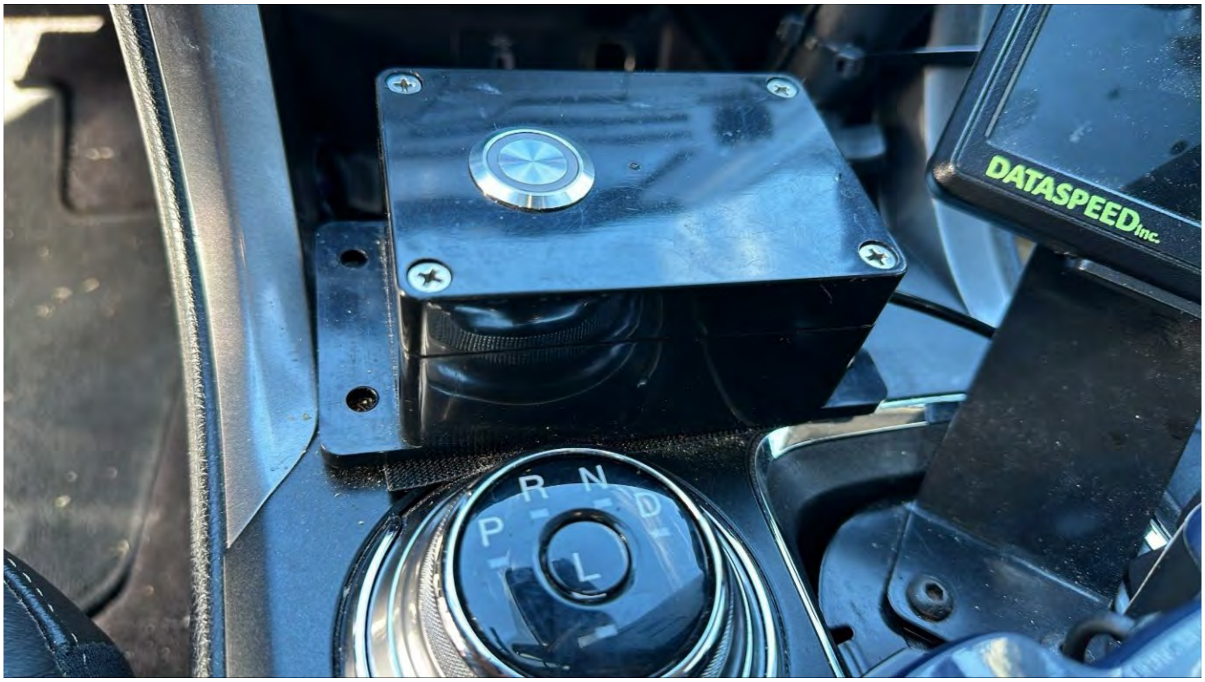

Figure 21: Button for engaging the ADS.

3.4.2 Recording disengagement reasons and other events

During the initial stages of deployment, it was observed that recording the reasons for disengagement was difficult in real time in a text file. Also, a separate text file does not contain timestamp or precise location of disengagement. To enhance logging of disengagement reasons and other notes from the operators, a ROS node was programmed by the TRC team to record the logs in audio format. The safety operator can trigger the 30s ROS node to start the audio recording. The safety operator based on the observation can record the reason for the disengagement. Being a ROS node, it had timestamp associated with the log.

3.4.3 Diagnostic Software Module (DSM)

During the CE testing, a critical diagnostic issue was identified. The ADS system can be engaged even when the critical modules and hardware like, GPS, camera and lidar are not launched properly. This issue was safety critical for the deployment on public road. A DSM was developed by the team which checks if all the critical hardware is launched, and the ROS topics are published at the correct frequency. If any hardware driver is not publishing the ROS topic at the correct frequency the ADS will not be engaged or if the ADS is engaged and any of the critical module software module crashed and stop publishing the topics the ADS will be disengaged by *DSM* and safety driver can take full control of the vehicle.

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3.5 Lessons Learned

- The ADS stack Autoware used in phase 1 had limitations in terms of predicting other agents' behavior that was evident from the CE testing and the public road deployment. The ADS stack can only be used in very limited ODD and needs an attentive safety driver to take control if any unsafe situation arises. Because of the limitations in predictions, the ADS was disengaged for any VRU in vicinity of ADS global path.
- The ADS can only operate in clear weather conditions. For one week during deployment, the ambient temperature was below 0 degree C and due to moisture freezing on the lidar, the ability of the ADS to detect obstacles was deteriorated. This caused the safety driver to disengage the ADS and drive only in bucket 2 or bucket 1 mode. If the ADS had any diagnostic to know the conditions of sensors, the disengagement can be automated instead of relying on safety driver to access the sensor conditions from the motion control feedback of ADS.
- The traffic light module was very sensitive to GPS orientation error. The map of Autoware ADS sends information to traffic light module where to look for traffic light in the camera frame. The location is dependent on the localization accuracy (specifically the orientation) of the vehicle (GPS determines this localization). During the deployment, it was observed that traffic light module is looking at the wrong segment of camera image and missing the traffic light. To rectify this, the rectangular section of the image where the camera image is segmented and sent to traffic light neural net was increased. Increasing the size of the rectangle helped in reducing the traffic light miss detections, but still the neural net caused some errors in determining the correct state of the light.

4 Phase 2 Deployment

During the phase-1 deployments in central Ohio, a few limitations of Autoware were identified. For example, Autoware is not capable of planning routes that required lane changes. Hence, the routes were required to be mostly single lane roads. Similarly, Autoware was limited to speeds less than 35mph. On the other hand, Apollo software stack is capable of performing lane changes and is not limited by the speed. The traffic light module of Autoware was also very sensitive to small GPS error causing camera segmentation to miss traffic light position in the scene. The traffic light segmentation was better in Apollo because of better cropping techniques. Also, Apollo provides a more versatile user interface through Dreamview which allows setting start and end points for planning, visualize data while driving, log driver/operator notes, etc. Although Apollo is based on less commonly used protobuf, the CyberRT tool allows basic data visualization, analysis, and extraction of data into other formats. Autoware on the other hand is ROS-1 based, and many off-the-shelf tools like FoxGlove are available for data processing.

For these reasons, the team decided to use Apollo based ADS platform for the phase-2 deployments.

4.1 Planning

As mentioned earlier in the report, in this phase 3 routes (Red, Blue, and Green) were chosen for deployment. After map verification, the system was engaged into autonomous mode and the intention was to collect data from entire route without interruption. Due to different routes, multiple vehicles and different driving modes, there were three decision variables for each deployment as mentioned in the table, below.

Table 14: Experiment variables for deployment

Route	Green, Red, Blue
Vehicles	TRC_Van1, TRC_Van2, FordFusion, Multiple Vehicles
Driving mode	Shadow-mode, Autonomous

The deployments were carefully planned to ensure data correctness and to add value to the general project keeping the project goals in mind. The team took the safety of the vehicle occupants, external vehicles, and people around the vehicle very seriously. A safety plan was prepared after controlled environment testing. Every deployment event was a 3-day event including planning, driving to the routes, deployment, data collection, data integrity checks, data upload and reporting lessons learned from the deployment. Depending on the deployment events and system behavior, the next deployment was planned, or system improvements were made to address any technical issues.

In this subsection of the report, we first provide a summary of safety operation plan and then details of a typical deployment day.

4.1.1 Safety Management Plan

In this project, safety was of paramount importance and given the highest. The drivers were instructed to disengage from autonomous mode and to take over the control for any situation perceived as risky or when in doubt.

Prevention of potentially dangerous situations is obviously ideal, but the nature of the new technology is that situations requiring immediate intervention may still unexpectedly arise. Top priority is to maintain safe operation by anticipating and preventing incidents. If an incident should happen, the people and systems involved should be prepared to handle them to mitigate injuries and damage, as well as to be able to follow up with appropriate discourse after-the-fact, if need be.

It was noticed during CE testing and initial deployment that at least 3 people (driver and two ADS-operators) are required during deployment. One of the two ADS operators was expected to keep attention to the traffic, Apollo's object detections in Dreamview, traffic light detections and other modules. The second operator's job was to keep track of data logging, CPU usage and other system performance measures. The following guidelines were adopted for the drivers during ADS deployments.

- **Expectations when driving with ADS enabled:**
  - Stay engaged in the driving task, be aware of your surroundings and path/speed of the vehicle.
  - This will require more focus than normal driving, because the vehicles actions could be unpredictable, so you need to keep alert for both surrounding environment and your vehicle.
  - Assess for yourself that you are able to focus adequately.
  - Take breaks as needed.
- When driving Automated Driving Systems, use the ChAT method. ChAT conveys a two-way conversation where you are both responsible for acting.
  - Check – Check yourself, check for hazards, check all mirrors, and check your blind spots.
  - Assess – Assess your position, assess the road, assess the situation, and assess the next step.
  - Take Over – Focus on taking over the operational controls of the vehicle.
- When to disengage:
  - Safety is the number 1 priority. When in doubt, it is best for the driver to take over until the concern has been relieved.
  - Anytime when the driver feels that an unsafe situation is occurring or when the driver feels the system is not performing normally.
    - Examples of unsafe situations: Vehicle does not detect pedestrian or vehicle ahead (could be about to cross path), steering jerks to the right, vehicle brakes abruptly, or vehicle enters new environment outside of operation conditions (starts to rain or on ramp), or the vehicle is about to break a traffic law, or the vehicle fails to detect other road users in the blind spot.
  - Anytime the speed is above 35 mph, the system will not be able to detect a stopped or slower moving obstacle with sufficient headway distance to be able to come to a complete stop. If an obstacle is identified when traveling above 35 mph, the driver should disengage the system and regain control.
  - Traffic light detection errors: The vehicles will have two small lights in front of the driver to inform the driver of what color the system believes the traffic light to be. If the light does not match the traffic light color, the driver should disengage the system and take control of the vehicle.

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- The system cannot travel through roundabouts. The driver should disengage and take control when approaching a roundabout.
- At the initial engagement, the Apollo van will occasionally lock the steering. The van will accelerate normally; however, it will not maintain the lane center. When this happens, immediately disengage, restart Apollo, and replan the route.

4.1.2 Driver Training

The team developed a training program for drivers and ADS operators. The training program included the technical details of operating the vehicle in shadow and autonomous mode, getting familiar with the system performance, and experiencing few scenarios under controlled environment settings to 'feel' the ADS nominal operations. All the drivers and ADS operators were trained at TRC's SmartCenter with surrogate dummies as targets. The driver training also included instructions on what steps to take in the case of a crash.

4.1.3 Day Before Deployment

The team set a meeting time to Monday afternoon of every week to decide the general goal of the deployment for the week including:

- Check for Weather.
  - Weather in the area of deployment is very important. As discussed in the ODD definitions, the ADS platform is not expected to be operated under low road friction conditions. Hence local weather forecast was checked. If the weather was deemed to be unsafe for driving, the deployment was called off or if the weather was considered safe for manual driving, but not for autonomous driving then the deployment was carried in shadow mode.
- All pre-deployment checks are carried out as per a standard Vehicle Safety Inspection checklist.
  - As part of the pre-deployment checks, the LiDAR and camera calibrations also need to be confirmed. In this process, the side LiDARs were checked against the center LiDAR as the center LiDAR mount is more firmly fixed. For camera mounts, reference lines were drawn on each joint to quickly find if the mount was loose or moved. If the LiDARs were off or camera mount is loosened, a standard calibration procedure was followed. This procedure was prepared with the help from AutonomoStuff.
- System and Hard disk check for space.
  - Clear the files in the below locations to clear the log and core files related to Apollo.
    - apollo/data/log
    - apollo/data/core

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    - apollo/data/GPSbin
  - Rebuild Apollo after clearing these files.
  - After clearing the files, the van should have a minimum of 80GB space in the internal drive.
  - Always carry one or two 1TB SSDs to transfer the files after each run.
    - *NOTE: each run on red and blue routes are approximately 80GB to 90GB each.*
- Planning of Vehicle(s) and Route.
  - The vehicles and the route are planned by looking at the previous data from the deployment tracker and the number of deployments on each vehicle for each route, the decides on which vehicle(s) to be taken for deployment. Other deciding factors are the vehicle(s) condition, special requests from the team, and the availability of team members for the day.
  - A typical deployment practice is for every 2 deployment days each on blue and red routes, one deployment on green route is carried out.
- Team travel for deployment.
  - Based on the team's availability, the deployment is carried out.
  - For the Vans (Van1, Van2) to be on autonomous mode, a three-person team is required to be on deployment. A trained driver, an operator, and a safety co-operator.
  - For the Vans (Van1, Van2) to be on shadow mode, two-person team is required to be on deployment. A trained driver and an operator.
  - For the Fusion to be on shadow mode, one person can manage the deployment.
- Always check with the team on Monday meetings (or weekly meetings) if any additional data to be collected during the deployment (like U-Blox) or if the team has any special requests.

4.1.4 Deployment Day

The deployment team, including drivers and ADS operators would reach TRC SMARTCenter in the morning to pick up the intended van(s) for the deployment. The day would start with quick checks before the deployment, including the data storage space and fuel range. The team would then drive the van(s) to the intended route in SE Ohio.

- A typical deployment started with loading the correct/latest version of the map and planning the route.
- Before starting a run, a metadata(.json) file was created using the metadata logging app described in section 4.3.2.

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- During the deployment if the driver must disengage, the reasons were logged in the Dreamview using the disengagement reasons tab described in section 4.3.3.
- The data for each run was moved to a folder with the name of Unix Timestamp, the Unix Timestamp was taken from the meta data file name. A sample folder structure is shown in Figure 22.

TRCVan2	--	Unknown
1691678548	--	Unknown
20230810104912.record.00000	1.7 GiB	8/15/2023 9:43:12 AM
20230810104912.record.00001	1.9 GiB	8/15/2023 9:43:18 AM
20230810104912.record.00002	1.7 GiB	8/15/2023 9:43:14 AM
20230810104912.record.00003	1.5 GiB	8/15/2023 9:46:46 AM
20230810104912.record.00004	1.6 GiB	8/15/2023 9:46:50 AM
20230810104912.record.00005	1.8 GiB	8/15/2023 9:47:02 AM
20230810104912.record.00006	1.6 GiB	8/15/2023 9:50:10 AM
20230810104912.record.00007	1.6 GiB	8/15/2023 9:50:23 AM
20230810104912.record.00008	1.5 GiB	8/15/2023 11:18:49 AM
20230810104912.record.00009	1.6 GiB	8/15/2023 9:53:24 AM
20230810104912.record.00010	1.8 GiB	8/15/2023 9:53:53 AM
20230810104912.record.00011	1.4 GiB	8/15/2023 9:55:23 AM
20230810104912.record.00012	962.1 MiB	8/15/2023 9:55:16 AM
Van2_1691678548.json	376 B	8/15/2023 9:55:48 AM

Figure 22: Folder structure for organizing deployment data

After the deployment was done for the day (i.e. around 4PM), the deployment team would drive the vehicle(s) back to TRC SMARTCenter for safe parking and data transfer.

4.1.5 Day after Deployment (Data Integrity and Upload)

The day after deployment was dedicated to data transfer, notes management, and feedback to the team about the deployment. During the deployment, the data was stored on external hard drives. These hard drives were then connected to a computer with fast internet access to upload data to AWS-S3 bucket. Post deployment all the data collected was uploaded to the AWS-S3 using the cyberduck. A sample of folder structure is shown in Figure 23. All the deployment notes were also uploaded in ASANA board for the project team to view.

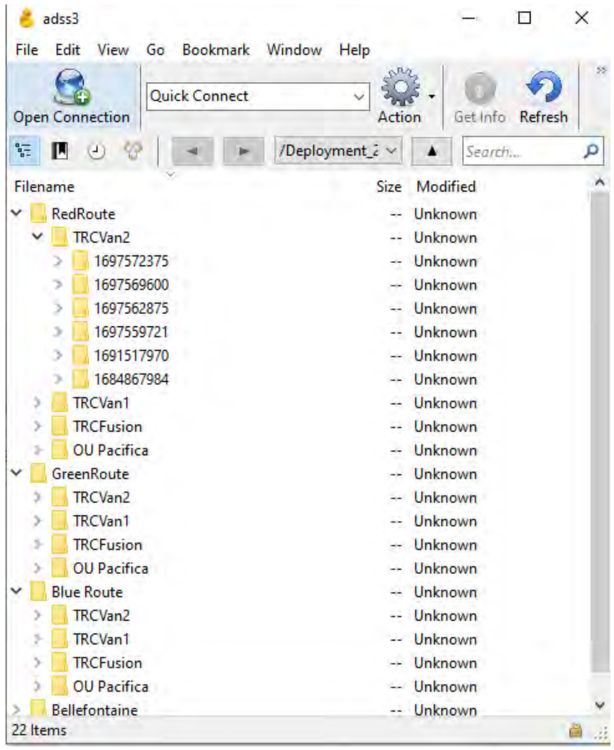

Figure 23: Cyberduck app used to upload data to AWS - S3

4.2 Data Management and Analysis Methods

4.2.1 Cyberbag data

Unlike Autoware which is based on ROS, Apollo uses protobuf as a language for communication between modules and data storage. The files generated from Apollo that store data are called cyberbags. These cyberbag files can be run inside Apollo docker and the data can be viewed in Dreamview. The team used this feature to replay recorded data, visualize data from different sensors including camera and LiDAR, visualize bounding boxes generated by object detection algorithms and evaluate key performance issues by eyeballing the replayed data.

However, customized data analysis is not immediately feasible with the data stored in cyberbag format. There is one open-source tool called ros-bridge to covert cyberbags into ROS. This ros-bridge has a message sender and a module that subscribes to all the messages and saves into rosbag. The message sender runs the cyberbag and reads messages. The issue with this approach is that there were dropped messages. Especially when running the bridge on a low read/write speed disk, a significantly large number of messages were lost. Hence, a process that does not rely on running the cyberbags was necessary.

Apollo Cyber RT is an open source, high performance runtime framework designed specifically for autonomous driving platforms. Cyber RT provides an array of utilities for the cyberbag files.

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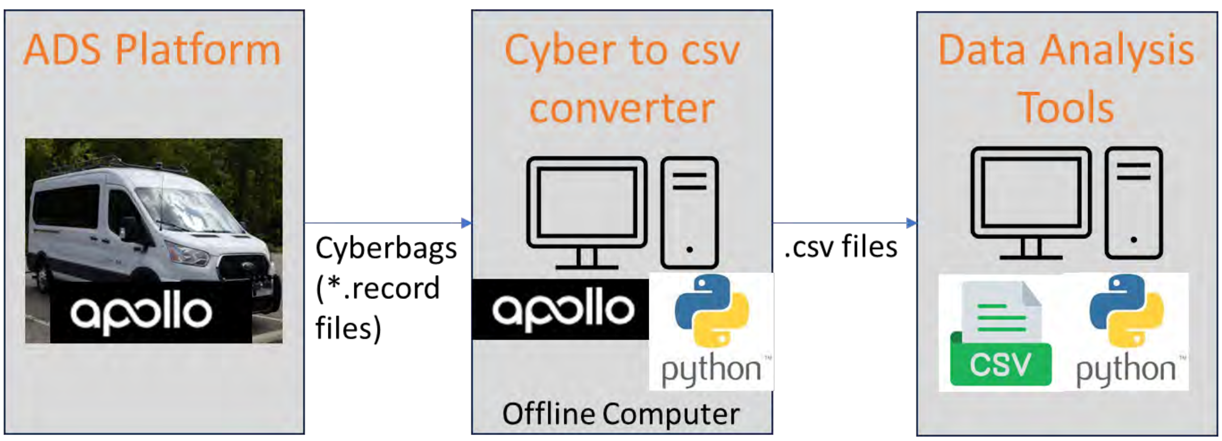
The TRC team developed a module in Apollo using Cyber RT and protobuf protocols to extract messages from cyberbag files and write those in csv (comma separated table) format. This tool reads the file one message at a time instead of running the file in Apollo. This way if a specific message takes longer time to read, the extraction takes longer time instead of dropping messages.

This module was used for extracting the data from necessary channels into csv format which is easily readable in many data analysis tools. The TRC team used python programs to filter, interpolate, analyze, and plot data. All the data analysis conducted for CE testing used the same tool. Further, any data analysis done during deployments for system faults analysis and bug fixes was done using the same process.

The code is made available to public on github:
https://github.com/DriveOhioADS/cyber_parse.git

Diagram showing process flow of Apollo ADS Platform vehicle data from the cyberbags (*.record files) through Cyber to csv converter via python on offline computer so that the csv files can be leveraged by the Data Analysis Tools.



4.2.2 HD Maps Data

HD maps for the routes contain vector map information for the route. The vector map definition format required by Apollo is similar to OpenDrive, but there are slight differences. Although there are open-source tools to plot OpenDrive standardized map information, those tools cannot be readily applied to these files as their JSON schema is different. Being able to plot the lane lines, speed limits, and stop-bars (as defined in the HD map) was required for map verification and to understand the lane centering capabilities and differences between the two vans' ADS stack calibrations.

The TRC Team developed a Python-based tool using protobuf proto definitions used in Apollo to read information in the HD map files and plot lane lines, stop bar, and intersections. A sample of the vehicle trajectories plotted on an HD map using python Bokeh library is shown in Figure 24. The Bokeh plotting library can generate an html plot which has tools like zoom in and pan. This visualization method allows efficient review of vehicle trajectories.

Figure 24: Example of HD map plot using protobuf python library and Bokeh library.

4.2.3 Deployment data

During the deployment, data analysis was conducted using the cyber to csv converter, and python based scripts. However, towards the end of the project, the team maintained a minimal Mongo database for quick data visualization. Only "/apollo/drive_event", "/apollo/sensor/gnss/best_pose", and "/apollo/canbus/chassis" channels were extracted from the cyberbags and inserted into the database along with metadata for the run. Mongo charts dashboard was prepared for the ease of summary visualization. This allowed keeping track of disengagements, number of deployments, etc. Two sample bar-plots from the Mongo charts are shown in Figure 25.

Figure 25: Mongo charts dashboard to monitor deployments.

4.2.4 Data Visualization within Apollo

Apollo provides three different ways to visualize past recorded data – replaying the data in Dreamview, visualization of camera/LiDAR data in cyber_visualizer, and monitoring data on all the channels using cyber_monitor. Dreamview in Apollo provides an excellent visualization tool for data in real time as well as off-line. The TRC team frequently used this feature to visualize past data to find and understand anomalies or any out-of-order system behavior. It shows real-time display of some important channels, bounding boxes and tracks of the objects, HD map etc. A screenshot of the Dreamview is shown in Figure 26.

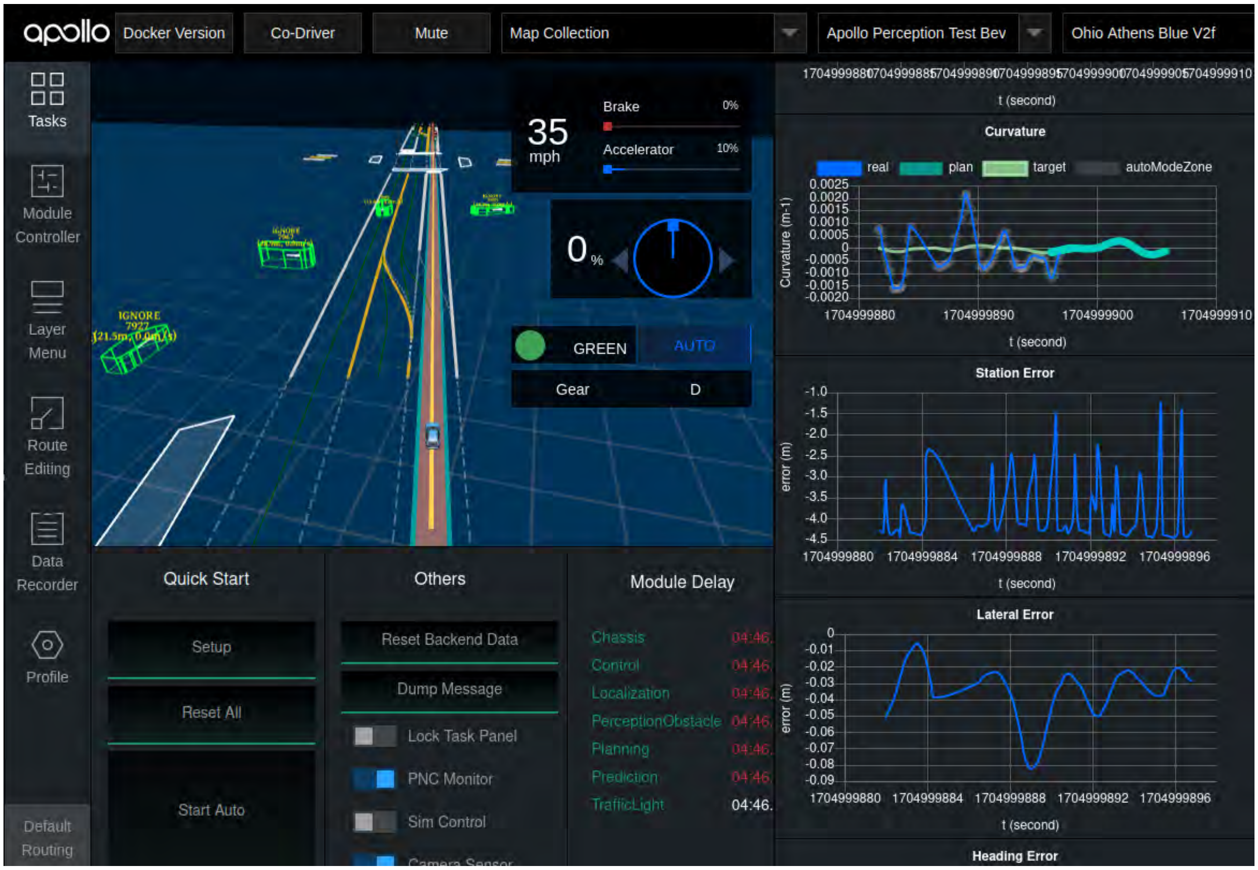


Figure 26: Data visualization in Dreamview.

Although Dreamview can provide all the data, it could become too cluttered in one window. Hence, a separate tool called cyber_visualizer was used to show camera and/or point cloud data. A sample screenshot of cyber_visualizer is shown in Figure 27.

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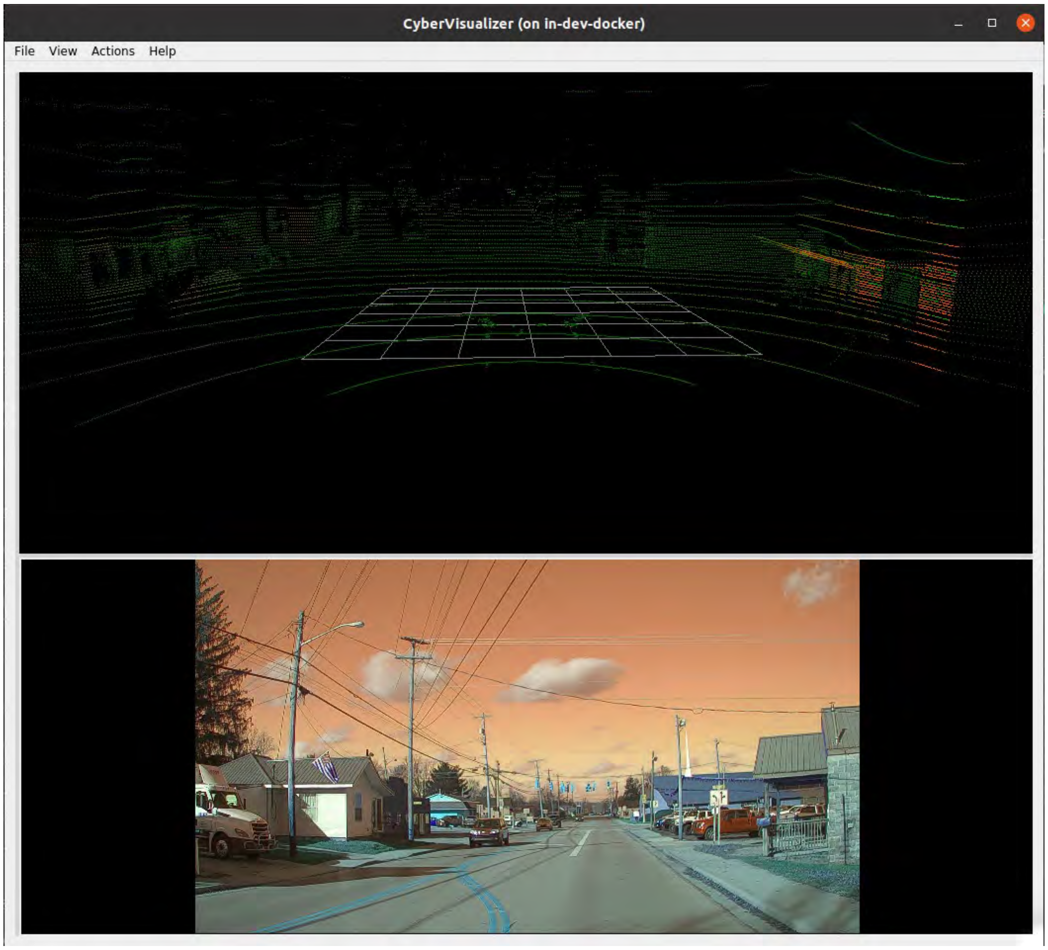

Figure 27: Cyber visualizer to see video and point-cloud data from past runs.

Besides Dreamview and cyber_visualizer, there is another tool to monitor specific channels and see the values being published or recorded. This tool is called cyber_monitor. It can print data in

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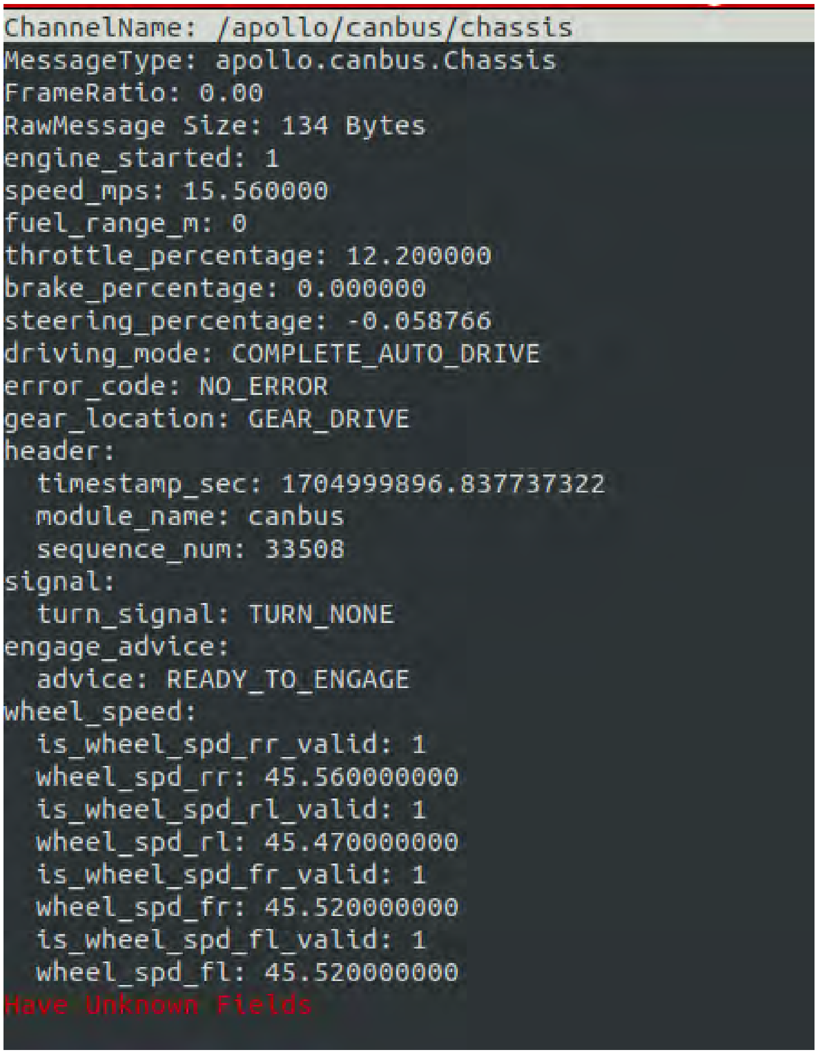
command line either in real-time on the vehicle or off-line by running a recorded file. A sample screen-shot of this command line tool being used to monitor chassis data is shown in Figure 28.



```
ChannelName: /apollo/canbus/chassis
MessageType: apollo.canbus.Chassis
FrameRatio: 0.00
RawMessage Size: 134 Bytes
engine_started: 1
speed_mps: 15.560000
fuel_range_m: 0
throttle_percentage: 12.200000
brake_percentage: 0.000000
steering_percentage: -0.058766
driving_mode: COMPLETE_AUTO_DRIVE
error_code: NO_ERROR
gear_location: GEAR_DRIVE
header:
  timestamp_sec: 1704999896.837737322
  module_name: canbus
  sequence_num: 33508
signal:
  turn_signal: TURN_NONE
engage_advice:
  advice: READY_TO_ENGAGE
wheel_speed:
  is_wheel_spd_rr_valid: 1
  wheel_spd_rr: 45.560000000
  is_wheel_spd_rl_valid: 1
  wheel_spd_rl: 45.470000000
  is_wheel_spd_fr_valid: 1
  wheel_spd_fr: 45.520000000
  is_wheel_spd_fl_valid: 1
  wheel_spd_fl: 45.520000000
Have Unknown Fields
```

Figure 28: An example of cyber_monitor being used to replay chassis data from recorded data.

4.3 Data Management/Analysis

Three types of data were generated from the southeast Ohio deployments. 1) data from the vehicle, ADS stack and disengagement reasons, 2) Metadata for each run, and 3) Notes from the drivers and operators about each run.

4.3.1 Vehicle Data

Apollo based ADS stack logs data in the form of cyberbags (or .record files). Each individual file was up to 2GB size. When the 2GB size was exceeded, a new file was automatically created. The files were automatically labeled as ‘<file name>.record.xxxxx, where xxxxx is a five digit number representing file number in the sequence starting from 00000. In other words, Apollo first creates a .record.00000 file, when it reaches approximately 2GB size, it creates a new file and names it .record.00001, and so on.

Before CE testing, it was found that data logging was limited due to read/write speeds of the data storage device and connecting ports. Hence, some data was discarded and not logged, for example raw image, raw CAN bus and rear LiDAR point-cloud data. Table 15 shows a full list of all the recorded channels during deployments.

Table 15: List of all the channels available in Apollo (on TRC Vans)

/apollo/monitor	/apollo/sensor/camera/front_6mm/image/compressed
/apollo/canbus/chassis	/apollo/sensor/camera/front_25mm/image/compressed
/apollo/canbus/chassis_detail	/apollo/control
/tf_static	/apollo/sensor/gnss/gnss_status
/tf	/apollo/sensor/gnss/ins_status
/apollo/localization/pose	/apollo/sensor/gnss/best_pose
/apollo/localization/msf_status	/apollo/sensor/gnss/corrected_imu
/apollo/monitor/system_status	/apollo/sensor/gnss/ins_stat
/apollo/common/latency_reports	/apollo/sensor/gnss/rtk_eph
/apollo/perception/obstacles	/apollo/sensor/gnss/rtk_obs
/apollo/planning	/apollo/sensor/gnss/heading
/apollo/routing_request	/apollo/sensor/gnss/imu
/apollo/routing_response	/apollo/sensor/gnss/odometry
/apollo/routing_response_history	/apollo/sensor/gnss/stream_status
/apollo/common/latency_records	/apollo/sensor/gnss/rtcm_data
/apollo/navigation	/apollo/hmi/status
/apollo/perception/traffic_light	/apollo/control/pad
/apollo/sensor/radar/front	/apollo/drive_event
/apollo/prediction	/apollo/sensor/velodyne16/front/right/PointCloud2
/apollo/prediction/perception_obstacles	/apollo/sensor/velodyne32/PointCloud2
	/apollo/sensor/velodyne16/front/left/PointCloud2

Most importantly, the driver disengagement reasons and notes were recorded using Dreamview and available in “/apollo/drive_event”. Apollo’s Dreamview provides a feature to record disengagement reasons. When driver decides to disengage, a drive_event menu pops up. This menu was updated by the TRC team to include additional buttons for common disengagement reasons as mentioned in section 4.4 on system improvements. This feature keeps timestamp associated with the disengagement event and when the driver/operator enters the reason and notes, it logs the data along with the timestamp. This allows tracking the disengagement reasons on the map. No separate notes for disengagements were kept during the deployment.

4.3.2 Metadata

Metadata for each individual run is of critical importance for data management and analysis. The drivers entered specifics of each run into a JSON file at the beginning of the run. A sample of metadata file is shown in the table below.

Table 16: Sample metadata file for TRC vans


```
{"metadata":
    {"driver": 3,
    "operator": 2,
    "vehicleID": "Van1",
    "Route": "Red",
    "Unix Time": "1706557888"},
"Other":
    {"Objective": "Single Vehicle Shadow-Mode",
    "Weather_Lighting": "Cloudy",
    "Weather_Precipitation": "No precipitation",
    "MapVersion": "V4",
    "StackVersion": "1.3.1"},
"file":
    {"type": "cyber",
    "folder": "Deployment_2_SEOhio/RedRoute/TRCVan1/1706557888",
    "filebase": ""}
}
```


Manually adding/typing entries for every deployment is cumbersome and prone to typing errors. Hence, the TRC team developed an app using python PyQt5 with drop-down menus and automation wherever possible. For example, the Unix timestamp for each run was taken from NovAtel directly. Similarly, the folder name was automatically generated from vehicle ID and Unix timestamp.

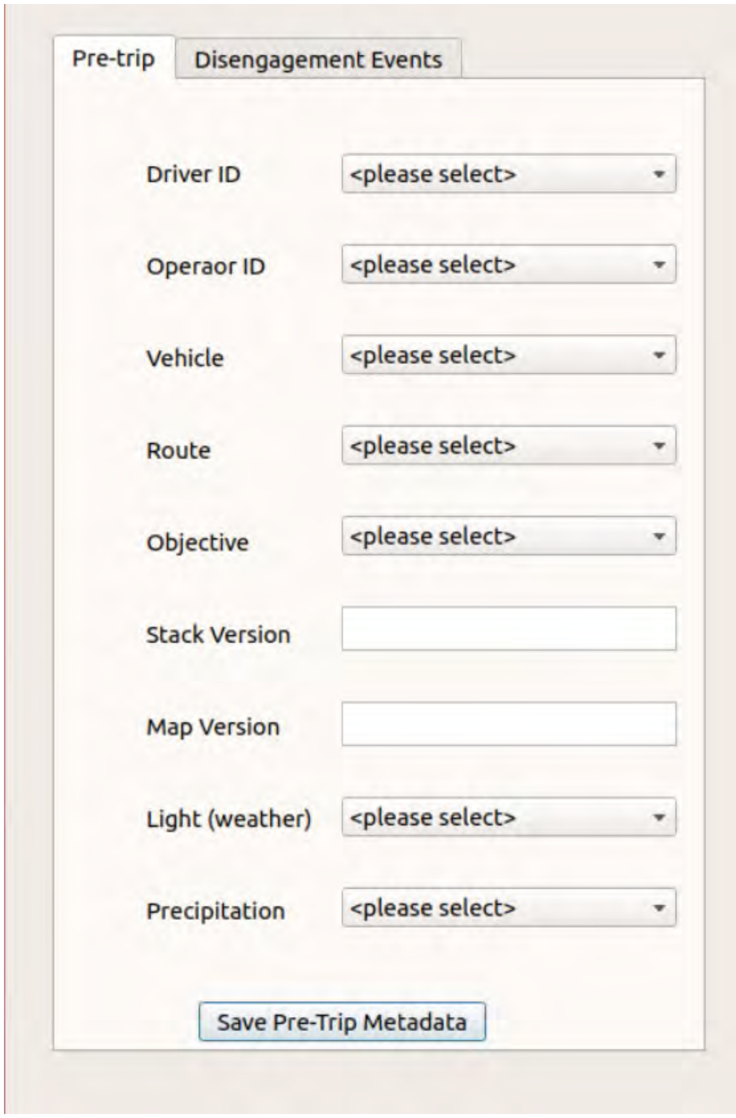


Figure 29: User interface of the app to create metadata JSON files.

4.3.3 Driver/Operator's Notes

The operators kept a notebook or note taking phone apps to take specific notes during the deployments. The notes included observations about the system behavior, interesting events, recommendations, etc. These notes were summarized into an Excel spreadsheet and then put into Asana board where they were shared with the entire team. A screenshot of one such deployment task on Asana board is shown in Figure 30. Future deployment related decisions regarding system upgrades, bug fixes and procedural changes were made based on these notes.

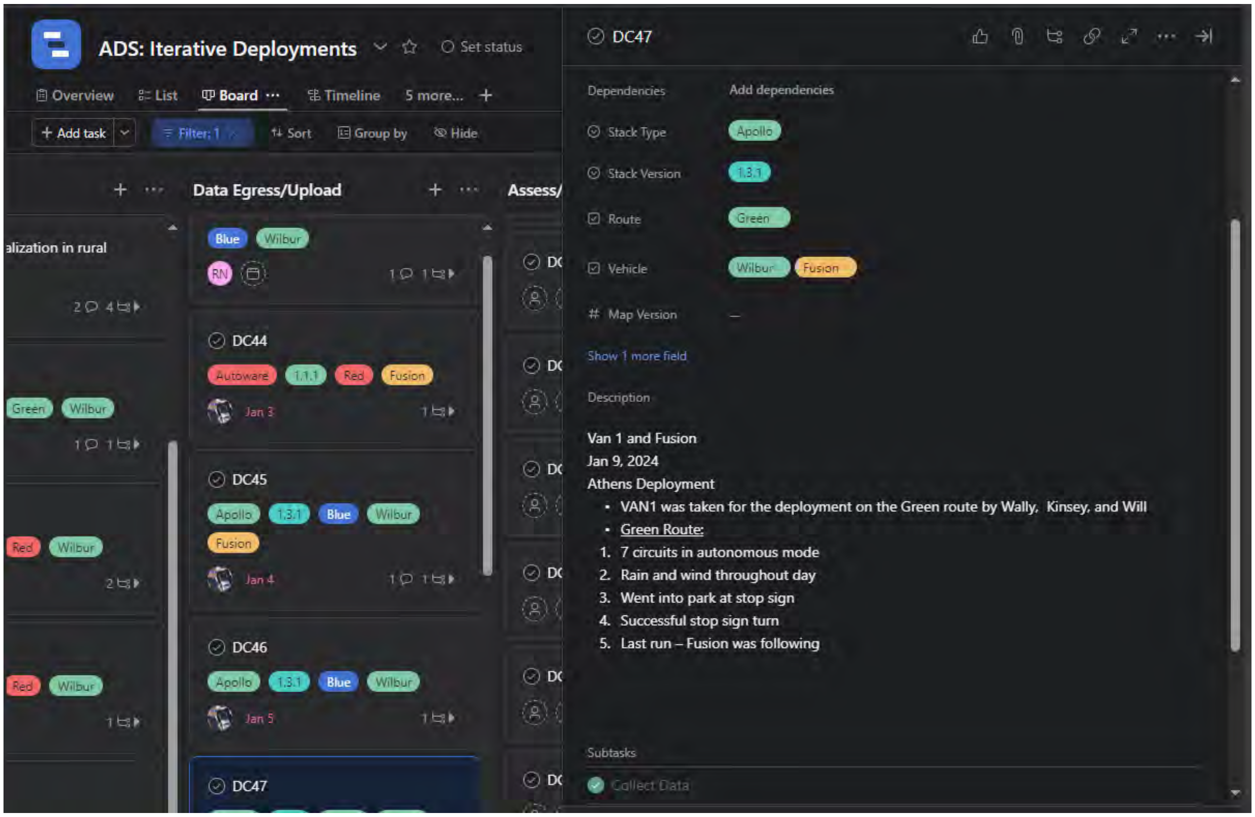


Figure 30: Screenshot of the ASANA board used to share deployment updates with the project team.

4.4 System Improvements and Bug Fixes

During CE testing and over the course of the deployments, we realized few system limitations that would have prevented from safe driving in autonomous mode. Some of those limitations were mitigated through driver training plan, but some were mitigated through system improvements. A summary of system improvements and corresponding stack version numbers are provided in the table below.

Table 17: ADS stack versions and corresponding upgrades made to the system

Date	Stack Version #	Title	Problem/Issue
5/29/2023	1.1.1	Obstacle Detection for Oncoming Traffic	Apollo will detect oncoming traffic as if it may be head on and apply the brakes and try to come to a complete stop unless manually over-ridden.
7/26/2023	1.1.2	LiDAR Calibration	Changed the yaw angle of the 32 LiDAR from 1.54 to 1.7
8/14/2023	1.2.1	Add Driver Event log buttons	Added driver event log buttons in the Dreamview. The disengagement reasons show up under driver_events/type data in cyberbag

Date	Stack Version #	Title	Problem/Issue
8/30/2023	1.2.2	Add driver events	Added driver disengagement events for: Intentional:11 and End of Route:12
9/11/2023	1.2.3	Add driver events	Add driver event for no disengagement interesting events
9/21/2023	1.2.4	Rebuild Apollo	System delay, high CPU usage
11/29/2023	1.3.1	Add automatic disengagement for high steering rate, loss of localization	High steering rate was observed a few times. Root cause not identified. Need to add a safety disengagement overhead module/code
12/12/2023	1.3.2	RADAR fixed	Van 1 Radar was not functional for all deployments before this.
12/15/2023	1.3.3	NovAtel Upgrade	Added other satellite constellations

4.4.1 Traffic light and localization accuracy indicator

Issue: It was noticed that the camera-based traffic light detection system was not highly reliable. The system may or may not recognize the traffic light correctly, and in case the system fails to correctly identify the signal, driver should disengage and control. Hence, it was necessary for the driver to know if the system was recognizing the traffic light. Similarly, in the rural environments, it was expected that the localization module may lose RTK corrections resulting in significant loss in localization accuracy. Without accurate location and heading of the vehicle, the system may veer off road. Although the Dreamview HMI displays perceived traffic light and localization accuracy in a small text message, the driver was not expected to pay attention to the HMI. Hence a more conspicuous display of perceived traffic light color and current localization accuracy was necessary in front of the driver.

Solution: The TRC team implemented a display with colored LEDs to indicate what traffic light color the Apollo's detection module was recognizing and if localization was accurate enough. The team developed a solution using an Arduino microcontroller. The microcontroller with clearly visible LED was fastened on the dashboard. The microcontroller was connected to the same WiFi as the Spectra computer to establish a communication channel. On the Spectra computer, which runs Apollo, a module named traffic light message sender was developed to send messages over the WiFi to the microcontroller. This module was built inside Apollo's docker container. This module subscribes to the traffic light messages and localization module messages. It constantly (at 5Hz) listens to any message sent by these modules. When it receives a message from localization module, it computes localization error using latitude and longitude standard deviation. If the error is more than a pre-set threshold or if it does not receive any message (meaning either localization module is not working, or it is not sending any messages) then a flag is raised. This module sends traffic light color information and localization module flags using UDP. On the microcontroller, a code was developed to read UDP messages and interpret them. Further, the code also activated appropriate LED pins to match the color of the LED with the color received in the UDP message. The Apollo software considers amber color of the traffic light as red, hence red/green LED colors indicate perceived traffic light color. If no message is received by the microcontroller (either due to loss of communication channel or failure to detect traffic light), the LED is kept off. It also changes color of a second LED depending on the localization flag. Figure 31 shows the architecture of the solution and Figure 32 shows the display fastened on the dashboard.

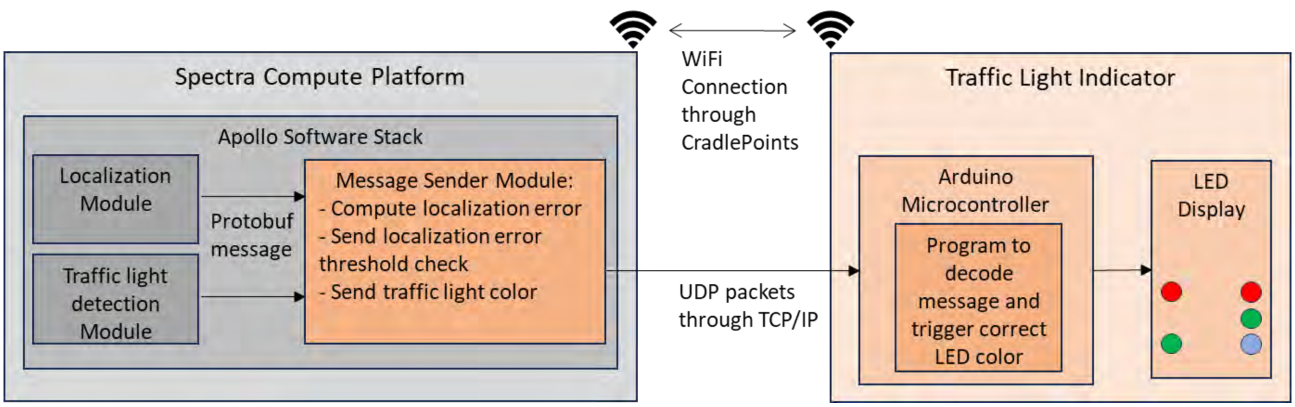


Figure 31: Dashboard traffic light indicator solution design.

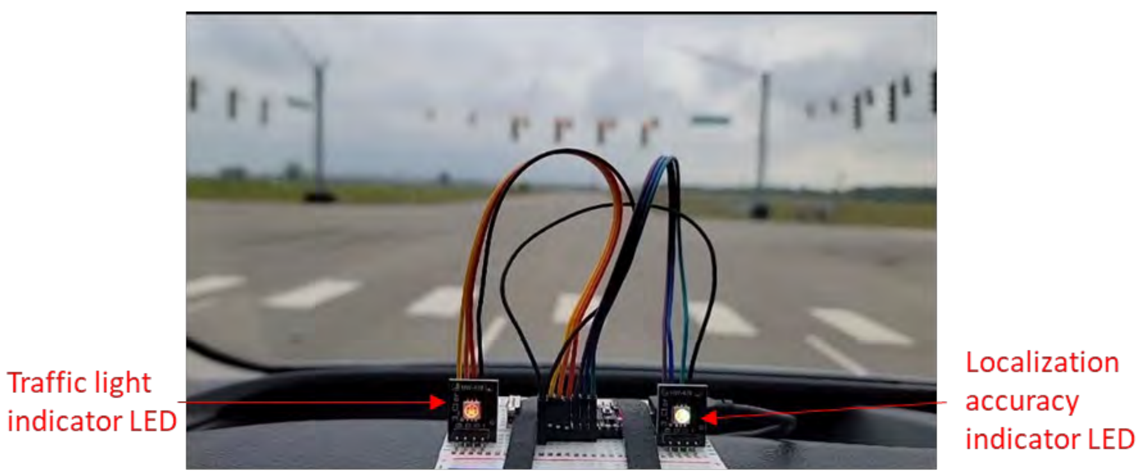


Figure 32: Traffic light and localization accuracy indicator display on the vehicle dashboard.

4.4.2 Disengagement Reasons Recorder

Issue: One of the goals of these deployments is to understand the difficulties in deploying automated vehicles in rural areas. Hence, the reasons behind disengagements are of pivotal importance. Furthermore, the disengagements and why the driver decided to disengage should be tagged with its location or time. Being a fully autonomous capable software stack, Apollo does not have a feature disengage automatically. Hence, we anticipated that all the disengagements will be initiated by the drivers. Apollo's Dreamview HMI has a feature that allows the operators to type disengagement reason and it gets logged along with the disengagement timestamp. However, this feature was not adaptable for general purpose use. For example, there were only three buttons with pre-set disengagement reasons, and it is not quickly feasible to add new buttons or change the reason code.

Solution: Although the Dreamview is not quickly editable, the software scripts are all open source. The TRC team used the JAVA script written for the Dreamview to reverse engineer the disengagement reasons recorder and edit the script to add new buttons. Also, the protobuf protocol for drive_event module was updated to add new codes for the additional buttons. During deployment, every time the driver disengaged, a popup would appear in the Dreamview to select disengagement reason and/or to type description of the event. This allowed the ADS operator to quickly select the most common disengagement reason after disengagement and the data was stored along with the timestamp at the time of disengagement. During the course of the deployment, more buttons for common disengagement reasons were added. Figure 33 shows the disengagement reasons panel in Apollo's Dreamview customized by the TRC team for rural deployments.

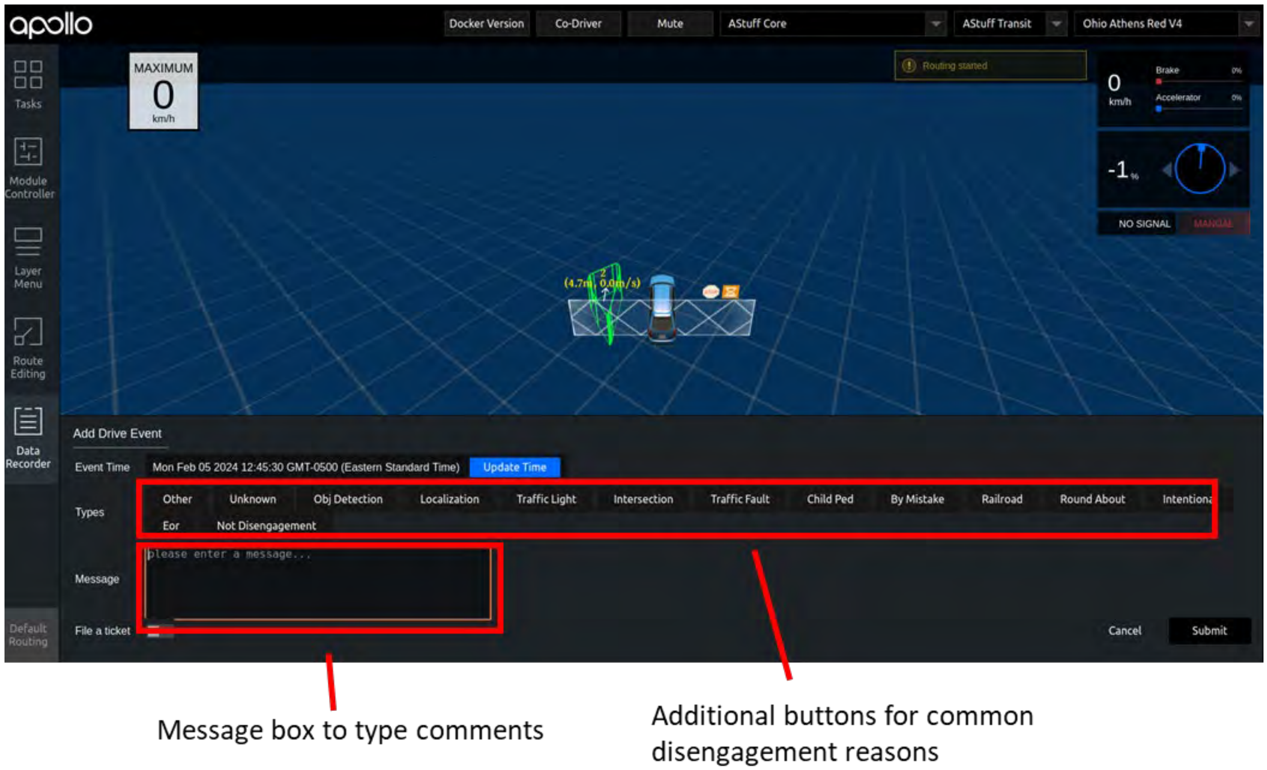


Figure 33: Panel customized by the TRC team to log driver disengagement reasons in Apollo's Dreamview.

4.4.3 High memory usage

The Spectra-2 compute system came with 256GB internal memory storage. Initially, it was thought to be sufficient for Apollo software. However, during CE testing, the used space in the disk gradually kept growing. This issue was found when the Spectra-2 could not reboot. It was found that Apollo dumps log files and does not remove those automatically. Monitoring the disk space and removing those files resolved the issue.

4.4.4 Lag due to high CPU usage

Issue: During the deployments in August 2023, it was found that the Dreamview display was lagging behind, the ADS platform was jerky when driving behind a lead vehicle, and deviated from the lane center on curved roads. It was also found that occasionally the control module was delayed. We also noticed that these issues were getting worse and more frequent as we conducted more deployments. These issues were more severe when a larger number of objects were being tracked by the software. Further, we noticed that the CPU usage was at 100% most of the times during the deployments. It was thought that the lag in the system was due to the high CPU usage. We started separately monitoring CPU usage during deployments.

Solution: After testing and monitoring the CPU usage for several deployments, it was found that Apollo docker container needs to be rebuilt often. After rebuilding the docker container, the CPU usage dropped down to around 60%. The lag in the ADS platform and Dreamview was significantly reduced and the vehicle behaved more reliably in traffic. Hence, starting from September 20th, 2023, we decided to rebuild Apollo every time log and dump files were erased from the memory.

4.4.5 Safety Control for High Lateral Acceleration

Issue: During the deployment, the team noticed a high steering rate on a straight road intermittently a few times. The driver took control quickly enough to avoid any crash. After one such event, it was decided that while the issue was being resolved, it was unsafe to drive in autonomous mode. After meticulous data analysis, it was found that there were two reasons behind this sudden high steering rate – localization module loss or errors and unbounded steering rate. It was found that the Apollo based ADS software would not disengage when localization module is unavailable or when localization has high error.

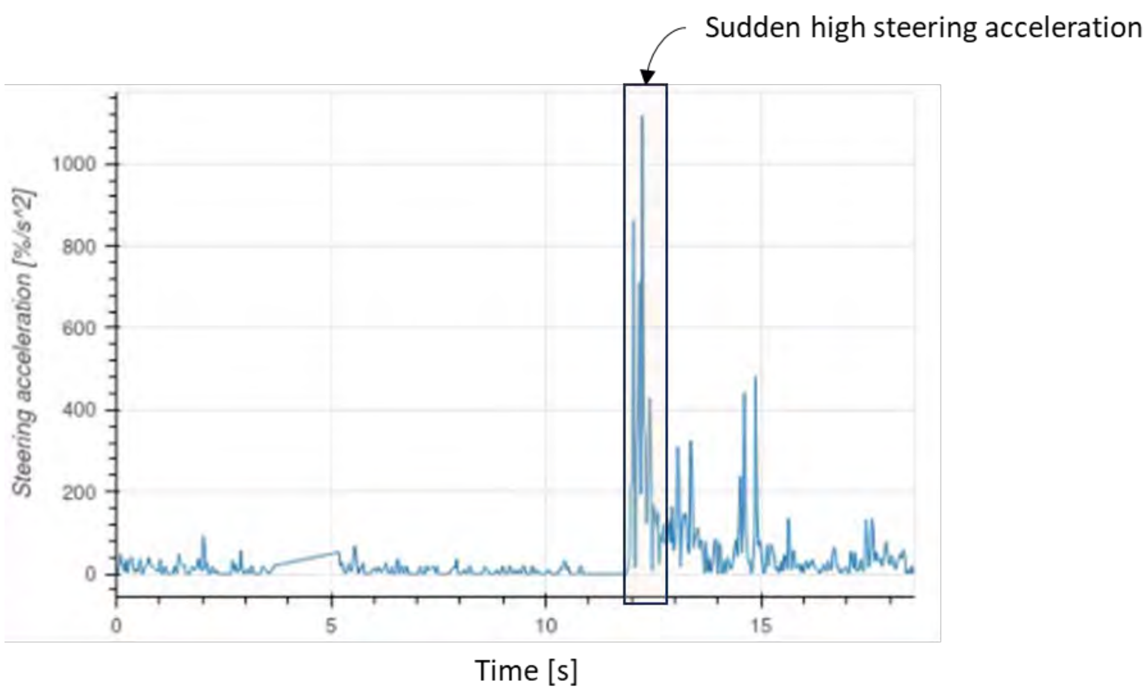


Figure 34: High Steering Acceleration

Solution: At first, the team attempted to add an upper bound on steering rate in the steering control module. However, adding a limit necessitates an anti-windup control. This would have led to a complete recalibration of the steering control. Since recalibration is time consuming and out of the scope, the team decided to force disengagement with a beeping sound when steering rate is greater than a pre-set threshold. During closed-track testing at TRC, the drivers found it easier to control the vehicle after automatic disengagement than taking control after sudden steering jerk. The maximum steering rate threshold depends on vehicle longitudinal speed. A data analysis was done using sample manual driving data to determine the typical speed dependent maximum steering rates. 99.98th percentile of the data in each speed range was used as the threshold. A patch of code was inserted in the chassis module that disengages the system for any commanded or actual steering rate greater than this threshold. Similarly, additional checks for the localization module were added. The system is set to disengage if localization became unavailable for one second. Figure 35 shows the sample data for steering rates obtained from manual driving on all 3 routes. In this figure, the red dots indicate 99.98th percentile of the data.

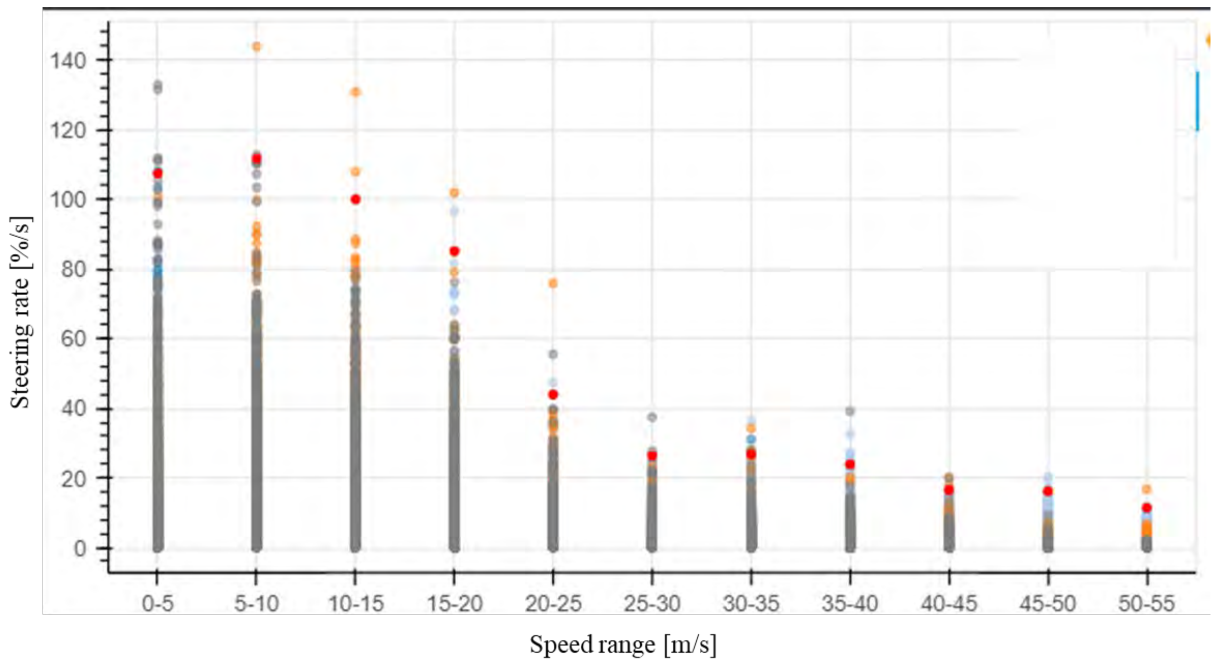


Figure 35: Steering rates from manually driven deployments on all 3 routes. The red dots indicate 99.98th percentile, and these values are used as threshold for steering rate at each speed range.

4.5 Addressing GNSS Issues on Rural Routes

4.5.1 Introduction

One of the primary challenges discovered during the rural ADS deployments was challenges to localization. The technology in the ADS vehicles we deployed relied heavily on localization to path plan, navigate intersections (including locating the traffic light), and to stay centered in the lane. All of this meant that having accurate heading and position was needed for the entire route. A horizontal accuracy of less than 0.5m was desired to confidently stay in the lane with the system engaged.

In order to achieve such a high accuracy reliably, several conditions must be met. Generally, the GNSS receiver must have the ability to use Real Time Kinematic (RTK) or, more recently, State

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Space Representation (SSR) corrections. These corrections tell the receiver how to correct for disturbances that could change how long the signal takes to come from a satellite, essential to calculate an accurate position. RTK corrections tend to yield a more accurate solution but require an internet connection or direct communication from a base station. SSR corrections can be broadcast from a satellite or an internet connection. Another technology that helps establish accurate positioning in case of dropout is an IMU, which after initialization can use the measured acceleration to compute position over time. The combination, known as an Inertial Navigation System (INS), allows the localization to continue even if there is a problem reaching an accurate solution from the GNSS alone. IMUs tend to be noisy and will only provide accurate solutions for up to a minute. Another technical aspect that affects performance is seeing enough satellites to effectively localize. Theoretically, this requires a minimum of four satellites in view, however, the minimum tends to be 10-14 to account for their placement in the sky allowing for sufficient spread to achieve the desired accuracy and an RTK solution. Today, there are four constellations from different nations/nation-groups that are available and using all of them will allow for the GNSS receiver to see a significantly higher number of satellites. Finally, to enable high accuracy heading angles a dual antenna configuration is possible with several GNSS /INS products. Dual antennas allow for the measurement of two points simultaneously to calculate the heading as opposed to relying on vehicle movement to obtain this measurement.

In addition to a reliable GNSS/INS, it is important to know the localization solution with respect to the HD map the vehicle is using. There are different map projections and understanding the information from the correction source and what was used for the map will be important to ensure there is not a fixed offset. Likewise, it is important to know the placement of the antennas to a high precision and have it configured correctly in the vehicle's settings, otherwise a fixed offset will exist from this as well.

Early deployments identified maintaining sufficient accuracy was a challenge for the vehicles' INS. Initial analysis discovered two reasons to be most likely the cause, insufficient visibility of the sky (not enough satellites in view) or lost corrections. Between these two, extended loss of visibility was the main culprit, leading to extended outages of more than a minute in valleys with dense tree coverage.

To understand the problem better and to attempt to solve it, low-cost high-performance development boards were acquired from U-Blox. These boards allow for highly configurable solutions to better understand settings that can best impact performance. In addition, one of the Transit vans' GNSS receivers were upgraded, through software, to be able to see more satellite constellations.

There are several other technologies still under development. These include terrestrial based positioning systems, third party satellite positioning systems, camera-based sensor fusion, and triple-band GNSS (addition of the L5 band). These solutions were not implemented during these deployments.

4.5.2 Equipment

U-Blox is the maker of several GNSS chips with a range of performances and capabilities. The two selected for this testing are in their high-performance category. The chips used were integrated into a single small prototyping board created by U-Blox themselves or a partner company, Ardusimple. Our integrations have paired this with an ESP-32 microcontroller to serve as an NTRIP/SSR client and a data logger. Two GNSS platforms were used one with and without an integrated IMU. These are low-cost units in the order of $100.

The Novatel was selected due to compatibility with the ADS stack, is a complete commercial product, and can be self-sufficient, without the need for a separate NTRIP client or data recorder, though a separate computer was used for storage of the provided positioning data. This is a higher cost unit, in the order of $10,000.

ZED F9P

The first unit used was the ZED-F9P, which has the capability to provide high accuracy GNSS position at up to 20Hz. By default, it can use all four GNSS constellations for positioning in the L1 and L2 bands. It can receive corrections, from either RTK using a local base station or from an NTRIP service, or from U-Blox's satellite-based service Thingstream. Thingstream uses SPARTN format to provide SSR type corrections to provide similar accuracy to RTK. The F9P is also able to use Satellite-based Augmentation System (SBAS) corrections, and this was enabled. However, these corrections to not provide sufficient information to achieve the desired accuracy. If two F9P units are used, then a dual antenna moving base operation is enabled. This was not used during deployments as high accuracy heading was not considered in this analysis but would be an important feature for use in ADS operation.

ZED-F9R

The second unit, the ZED-F9R, has similar characteristics to the ZED-F9P, but has an integrated IMU. Like the F9P, it can use all four GNSS constellations for positioning in the L1 and L2 bands. It can receive corrections, from either RTK using a local base station or from an NTRIP service, or from U-Blox's satellite-based service Thingstream. Thingstream uses SPARTN format to provide SSR type corrections to provide similar accuracy to RTK. The F9R is also able to receive SBAS corrections. The F9R, is only able to provide 1Hz position updates from the GNSS receiver but can use the IMU to provide a higher frequency 20Hz position update. Also, the F9R cannot receive RTCM 4072 messages, used for dual antenna or moving base configurations for high accuracy heading information. One aspect of this unit that was not used but would likely yield better performance is the ability to use the vehicle's wheel-ticks for improved accuracy during GNSS outage.

NovAtel PwrPak 7D-E2

The Novatel' GNSS+INS receiver is commercially packaged to provide a complete user interface, easy to use COM ports, Wi-Fi, and comes with drivers that integrate directly into the vehicle's driving platform. It also has a built-in NTRIP client. It has a tightly coupled IMU with the GNSS and using the IMU is able to provide updates up to 200Hz, though in our use this is 20Hz. It has a built-in dual-antenna capability enabling precise heading calculations. It uses the L1 and L2 bands from the GNSS constellations to calculate position. Initial configuration came with the GPS and GLONASS constellations, but for the van used in this analysis, it has been upgraded to include Galileo and BeiDou. In addition to receiving corrections from a base station, it can also receive satellite-based corrections from TerraStar, though this was unused.

Correction Sources

There were two types of corrections used in the deployment, Real-Time Kinematic (RTK) corrections, which use the RTCM (Radio Technical Commission for Maritime Services) format, and State Space Representation (SSR) corrections, which can be transmitted over various formats but done here using SPARTN encryption. To achieve RTK precision correction, data must be transmitted from a base station(s) with a known fixed location to the vehicle receiver in real-time. The connection can either be radio based, if local, or by using NTRIP to receive corrections from one or multiple base stations. This project used NTRIP for all RTCM corrections and used ODOT's virtual reference system (VRS). A VRS uses several base stations and provides a single interpolated set of correction data. This correction data helps enhance the accuracy of the rover's position determination by accounting for errors introduced by atmospheric disturbances and satellite orbit deviations. RTCM corrections typically include differential corrections for carrier phase measurements, aiding the rover in achieving cm-level positioning accuracy.

SSR corrections use a model-based approach that allow them to apply to a wider area and thus can more easily be transmitted via satellite but can also be provided over an internet connection. Our project used a service that was encrypted using a SPARTN format SSR corrections leverage regional or global navigation satellite systems to transmit correction data to GNSS receivers. These corrections typically encompass ionospheric delays, satellite clock errors, and orbit corrections, enabling cm-level positioning accuracy.

RTK sources were initially used in the U-Blox units, but with the goal of providing improved accuracy over that of the Novatel, which used RTCM, it was desired to incorporate satellite-based corrections to provide backup in the case of cellular dropout. The RTCM corrections did provide good performance but had the same gaps as the Novatel. The U-Blox was not able to seamlessly switch between SSR and RTCM corrections, therefore SSR-based corrections were used for all U-Blox units' data below and RTCM corrections were used for the Novatel.

Routes

As discussed in other sections of this report, the red, green, and blue routes were used as the basis for this analysis. These routes had several features that are challenging, yet typical in rural environments. Some of these features include poor cellular reception, tree coverage, steep ravines, and overpasses. The routes reviewed here are shown in *Figure 36*, *Figure 37*, and *Figure 38*. Each though geographically near each other provided different challenges as shown in the figures. The red route had hills, trees, a portion of the route without strong cellular reception. The blue route had a mixed route with both urban buildings next to the road and trees. The green route had some portions with tree coverage, but was more flat and also passed through low-tree farmed areas.

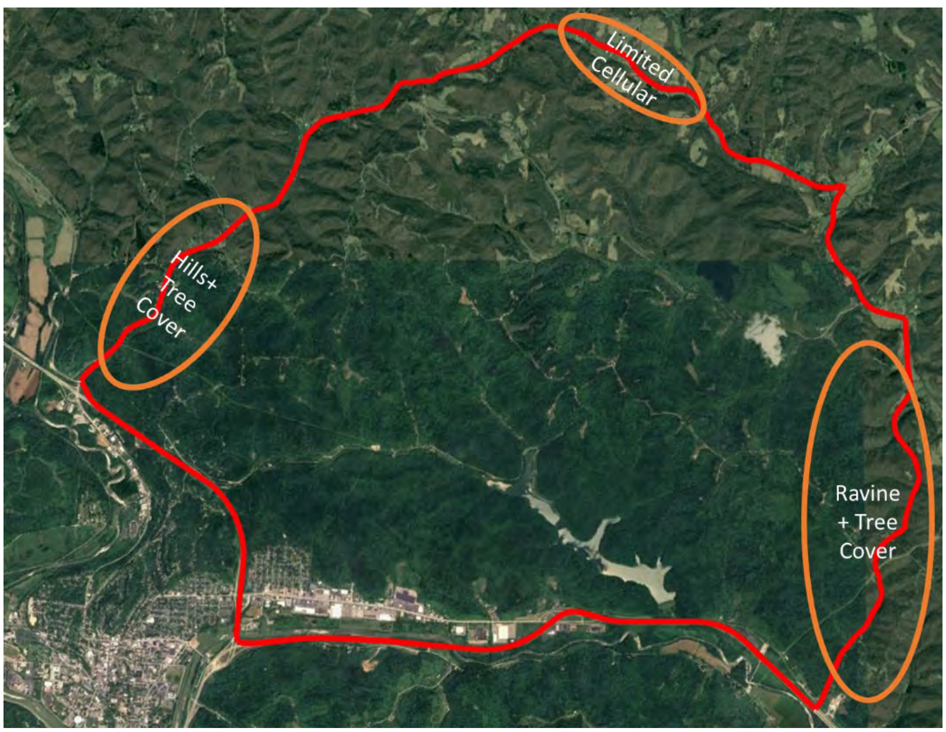

Figure 36. Red route, passes through rural and hilly areas with lots of tree cover.

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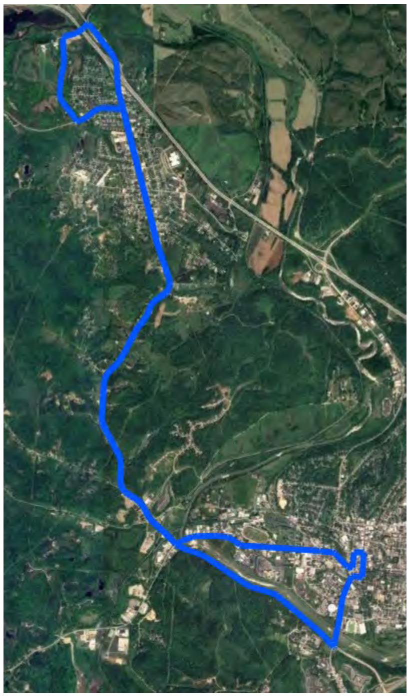

Figure 37. Blue route, passes through semi-urban and rural areas with tree cover and some potential for multi-path interference.

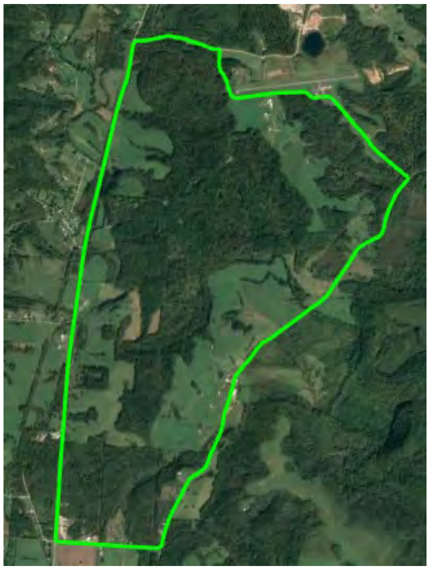

Figure 38. Green route, passes through rural areas with some tree cover and some farm areas without many trees.

4.5.3 Results

About seven hours of data was collected across all routes using different correction sources for the two types of U-Blox units, as summarized in Table 18. The table provides the percentage of measurements where the estimated accuracy was about 0.5m and 2m, respectively, as well as

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the max accuracy estimated on the route. Limited data was collected with only one correction source but is included in the table for some level of comparison but may be less statistically significant. The majority of the data was collected using the F9R.

Table 18. Summary of data collected, from the routes and correction sources for the U-Blox units.

	Red			Green			Blue		
	% >0.5	% >2	Max acc	% >0.5	% >2	Max acc	% >0.5	% >2	Max acc
F9P – Sat	0.65%	0	1.749m	6.0%	0	1.694m	3.4%	0%	1.719m
F9P – IP+Sat	0.92%	0	1.495m	0.18%	0	1.205m	0.061%	0	0.533m
F9R – IP	0.14%	0	1.086m				8.28%	0	1.329m
F9R – IP+Sat	0.40%	0	1.508m	0.81%	0	1.169m	1.60%	0.030%	2.605m

ZED-F9P Satellite vs IP

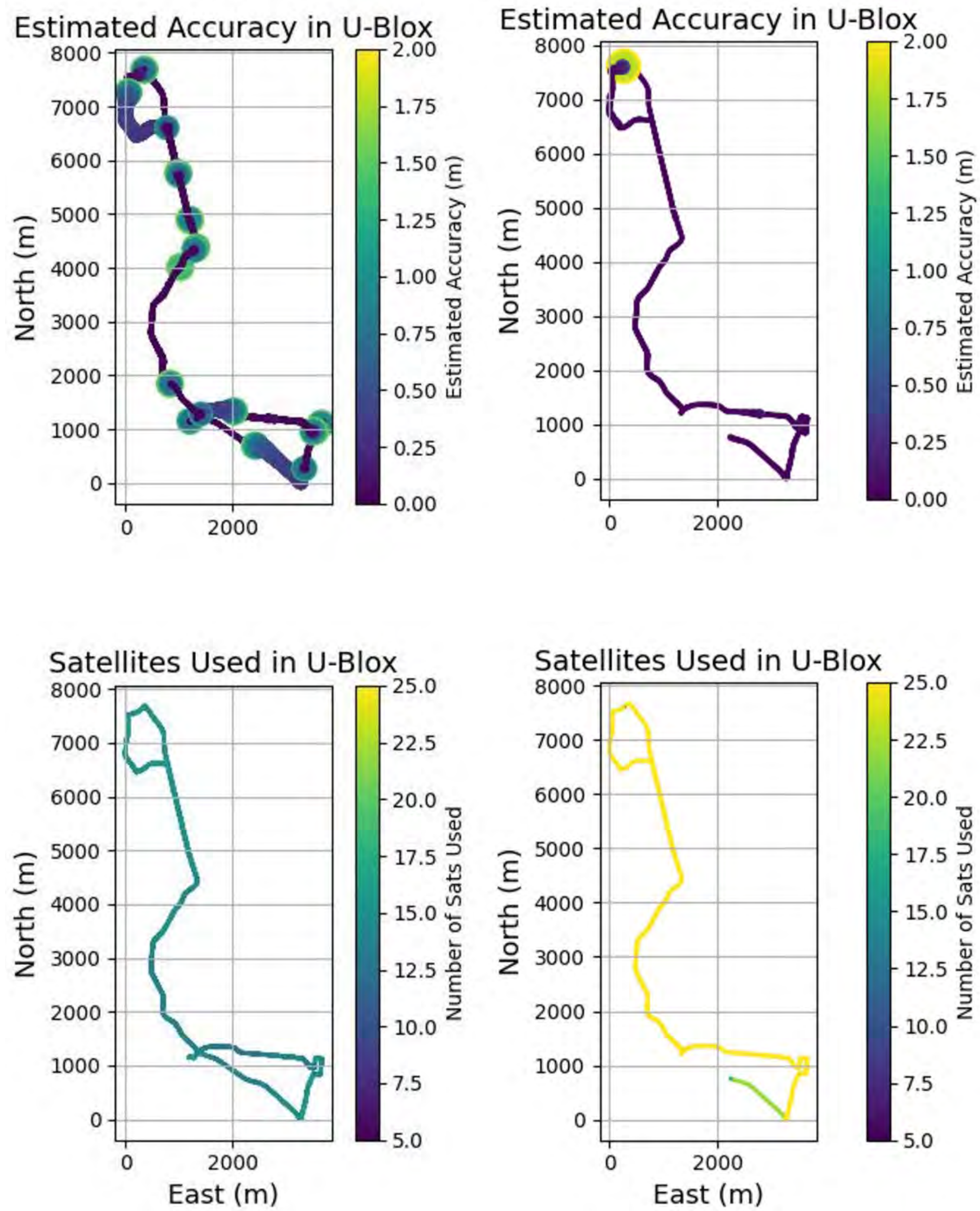

Figure 39. GNSS SSR corrections with satellite only (left) vs with internet only (right).

Figure 39 shows a comparison of corrections from satellite only and with internet only. The estimated accuracy is shown in the top plots using both the color scale and proportional to the size of the marker. The early deployments used a splitter to enable reception of corrections and the GNSS signals from a single antenna. This was seen to lower the ability to receive the corrections and also reduce the number of satellites with a usable signal, as seen in the bottom plots. The use of the splitter reduced the strength of both signals leading to reduced satellite's received (bottom-left). This was remedied as shown in Figure 40, where the satellite reception is strong throughout the route, even in challenging terrain. However, the terrain is still seen to affect the satellite only based corrections (without clear view of the sky) more than when using internet and satellite-based corrections, as seen with the more frequently reduced accuracy (larger circles) in the top-left. It should be noted that even though there is some loss of corrections, the estimated accuracy generally stays below 1.5m.

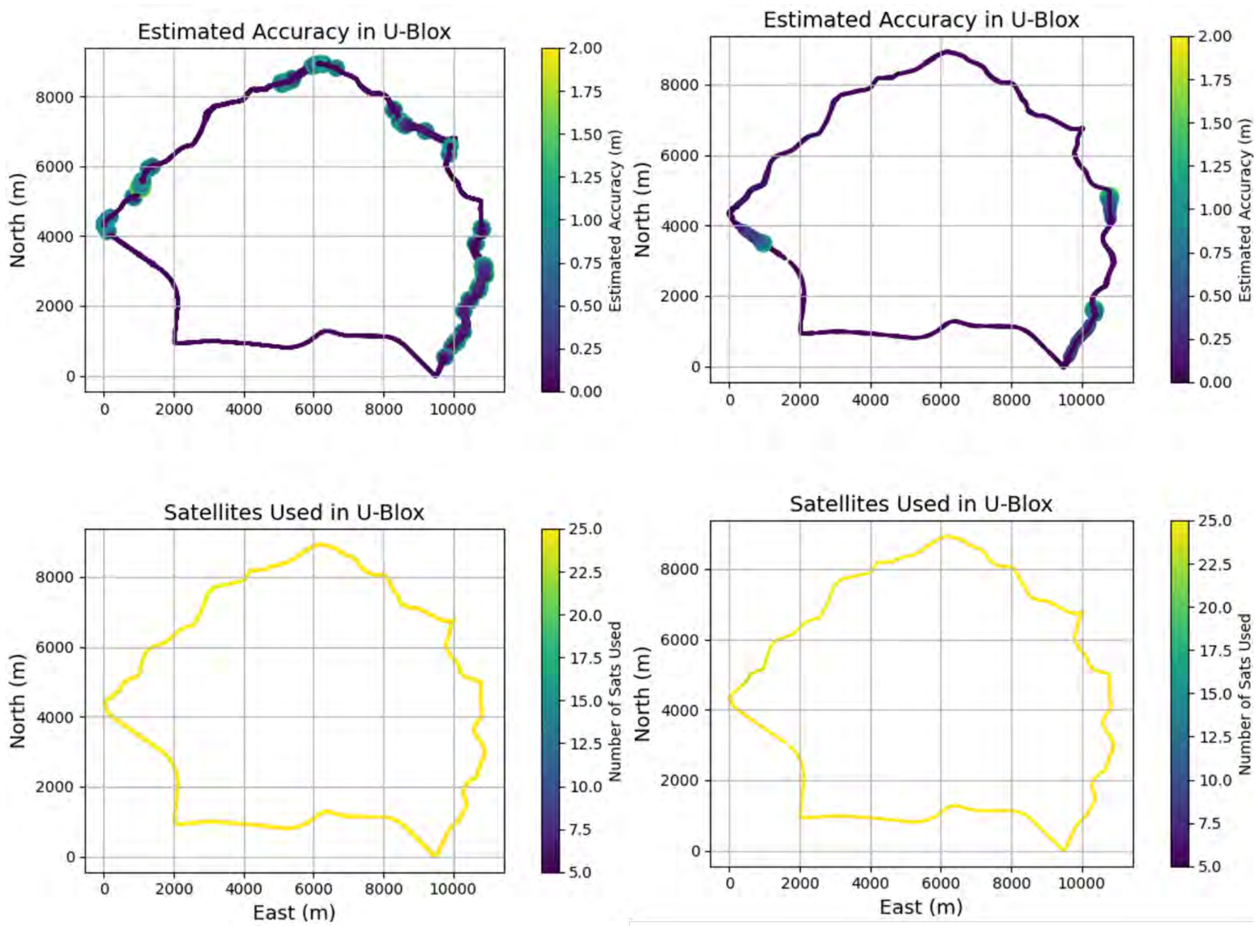

Figure 40. GNSS SSR corrections with satellite only (left) vs with IP and Satellite backup (right).

ZED-F9P SSR IP vs IP+Satellite

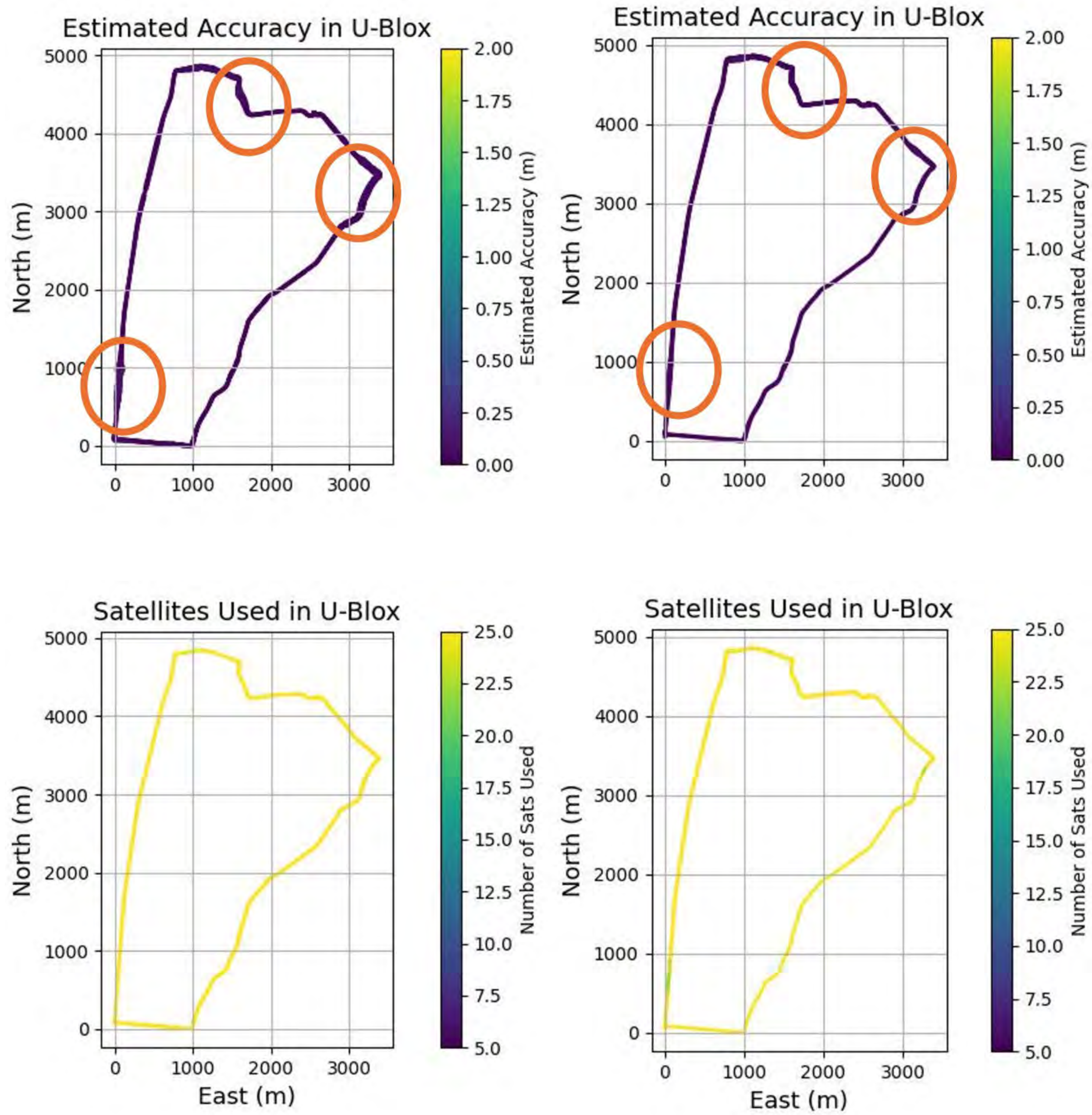

Figure 41. GNSS SSR corrections with internet only (left) vs with internet and satellite-based backup (right).

Figure 41 shows there is limited differences between internet only corrections and those with satellite-based backup. A few areas can be seen to maintain slightly lower accuracy, as shown by the orange circles.

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ZED-F9R SSR vs IP+Satellite

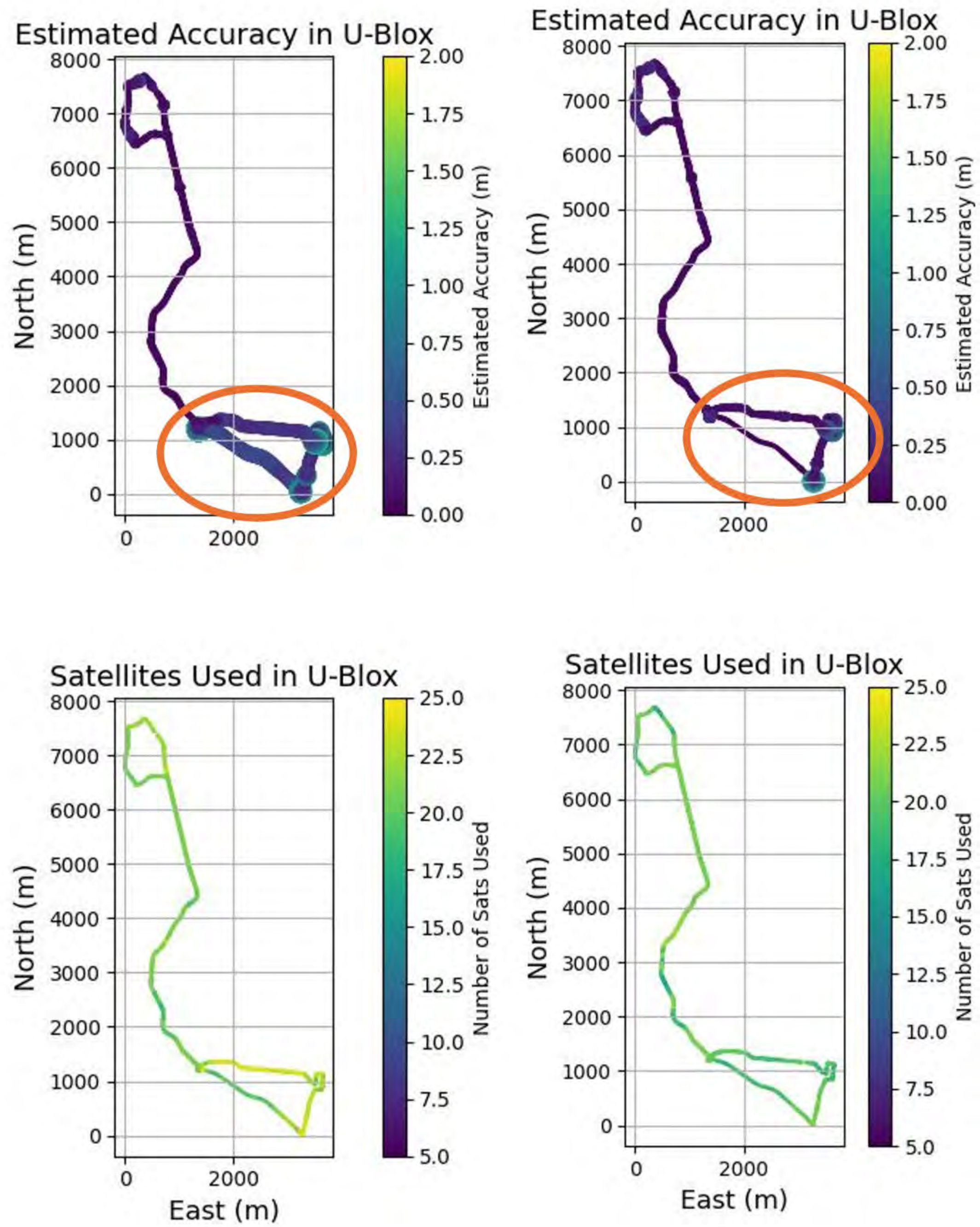

Figure 42. GNSS SSR corrections with internet only (left) vs with internet and satellite-based backup (right).

Figure 42 shows another route's difference between internet only based corrections and those with satellite-based backup. As can be seen, there is an improvement in performance by using the satellite-based backup in these runs.

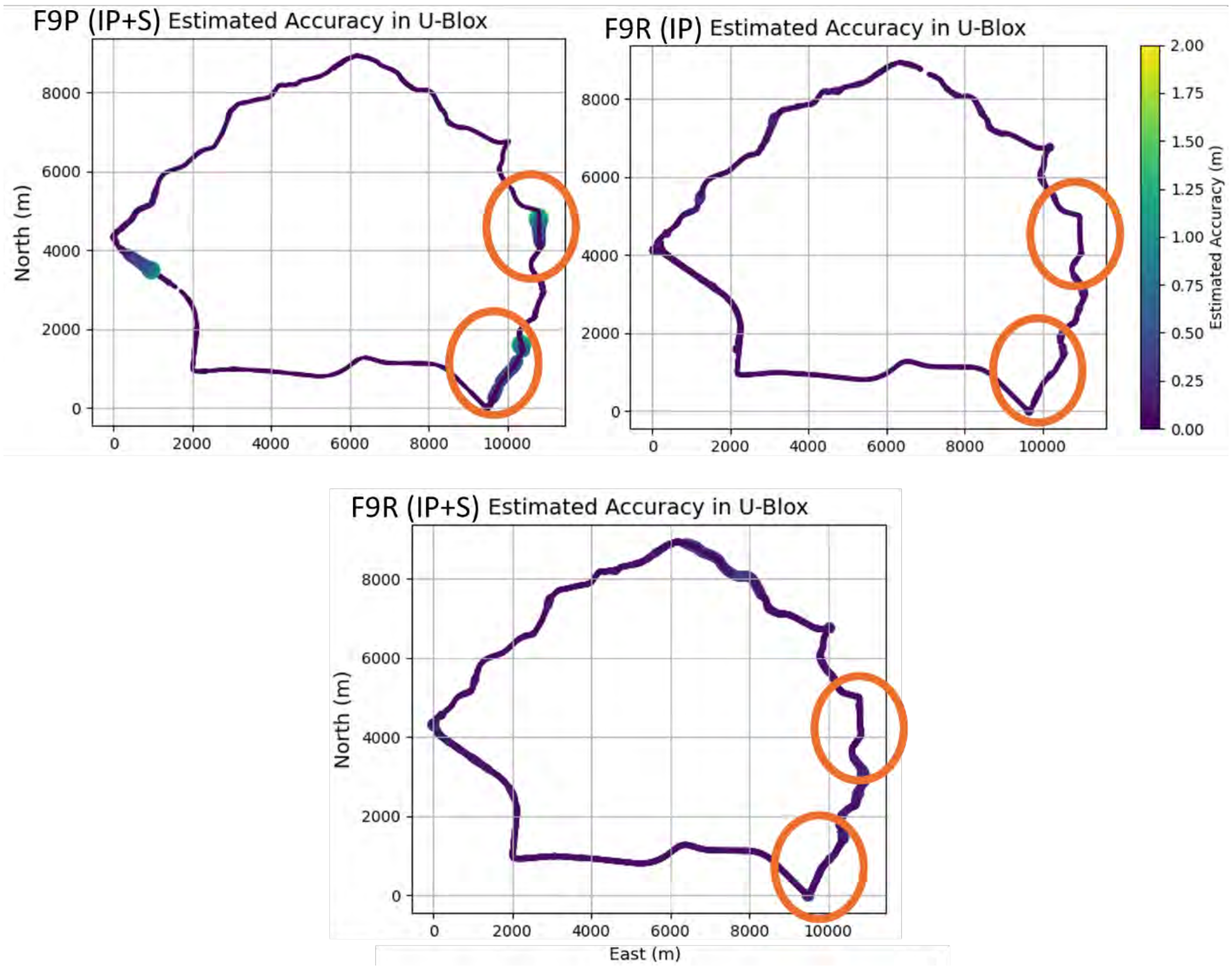

Figure 43. GNSS SSR corrections with internet and satellite-based backup using the F9P (top-left), with internet only using the F9R (top-right), and with internet and satellite-based backup using the F9R (bottom).

It can be seen in Figure 43, that without an IMU there are a few areas where accuracy was degraded, even with satellite-based backup, though not all the way up to 2m. However, the performance is much more robust in both of the IMU enhanced receivers, even the one without satellite-based backup. This can provide some insight into the priorities ADS developers will wish to take when integrating positioning solutions into their designs. Obviously, in deep ravines or in tunnels, both cellular and satellite-based corrections are not likely to come through, let alone the GNSS signals themselves. Therefore, an IMU is required to maintain tracking in these environments. Satellite-based backup provides redundancy but is not as critical in some situations.

Novatel GPS + GLONASS vs. Four Constellations

Novatel data was collected using the *BestPose* message and filtered by times that overlap with the U-Blox data collection. Below shows the significant improvement that occurred when the

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receivers were upgraded (via a paid software update). Table 19 provides a summary of the Novatel results, including the percentage of measurements where the estimated accuracy was about 0.5m and 2m, respectively, as well as the max accuracy estimated on the route. The Novatel was not as capable as the U-Blox unit despite the cost difference and each route showed significantly worse performance in time spend below 0.5m, below 2m, and accuracy experienced, as demonstrated in Table 19. There was close to a factor of 3x decrease in performance across all routes in each of these categories.

Table 19. Comparing a Novatel GNSS+INS receiver using two-constellations vs four-constellations.

	Red			Green			Blue		
Novatel	% >0.5	% >2	Max acc	% >0.5	% >2	Max acc	% >0.5	% >2	Max acc
Two Const.	9.297%	3.430%	35.4m	5.855%	1.366%	30.1m	2.986%	0.860%	75.1m
Four Const.	3.013%	0.351%	9.59m	2.841%	0.117%	14.1m	1.071%	0.543%	49.8m

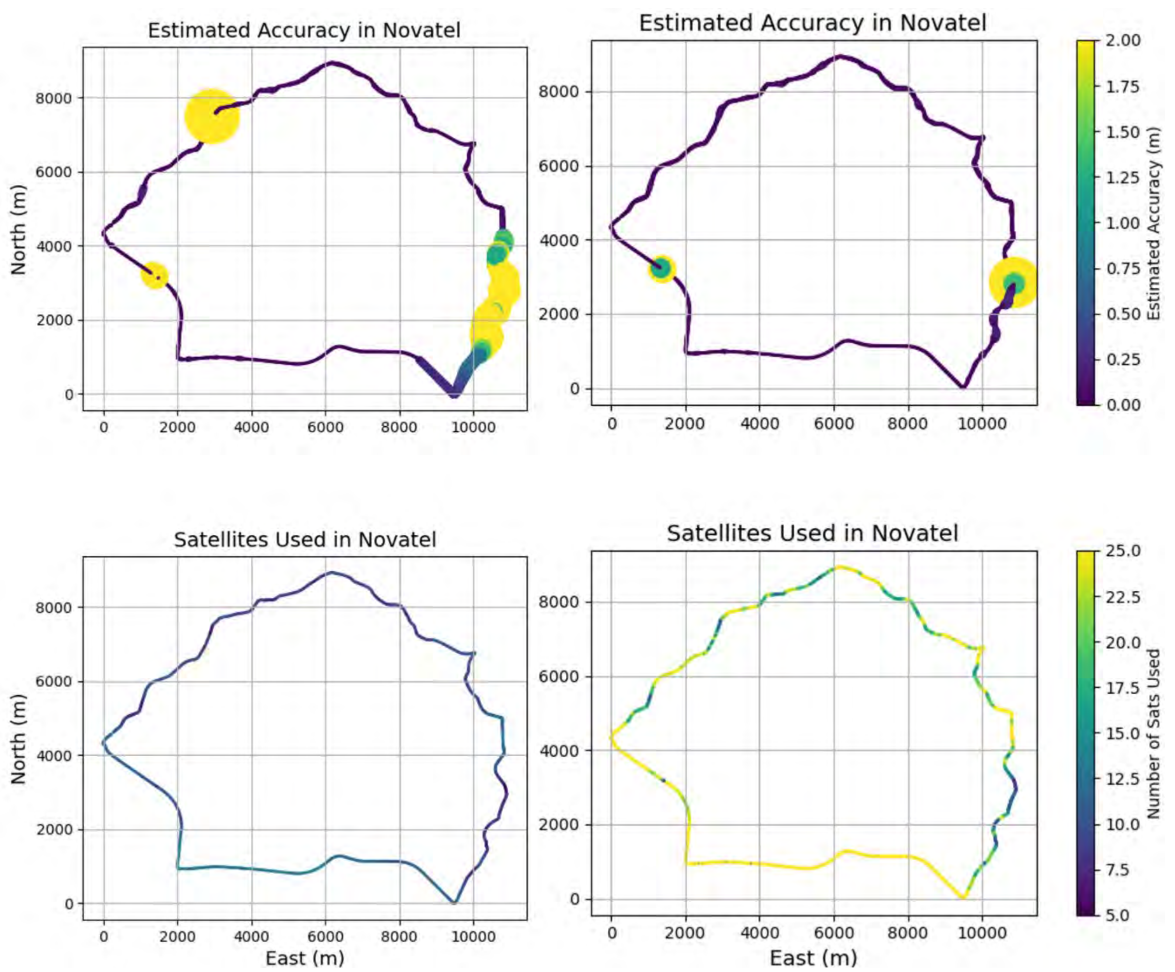

Figure 44. Novatel receiver using only GPS+GLONASS (left) and GPS+GLONASS+Galileo+BeiDou (right).

Figure 44 shows the difference between a Novatel unit when there are only two satellite constellations used compared to four. As can be seen, there is an improved performance in the Novatel between GPS+GLONASS (left) and when Galileo and BeiDou are added. In the ravine (bottom right portion of route), the Novatel still struggles to maintain enough satellites with all constellations using the Novatel but is able to recover more quickly and have a shorter total reception blackout area. It can be seen that the baseline satellites received are much higher throughout the route, which provides added redundancy to the system.

4.5.4 Conclusion

Rural environments exhibit several challenges for GNSS/INS systems, requiring comprehensive redundancy in terms of receiving the needed corrections to calculate precise location solutions and be able to operate under partial or complete satellite obstructions. Several different technologies were considered here and show it is possible to have low-cost position accuracy with improved performance.

Ultimately, the F9R provided the best performance, allowing high satellite reception, even in challenging areas, the ability to maintain accuracy through loss of GNSS signals or correction sources and is low-cost. Further integration needs to be done to attempt to incorporate the F9P and the F9R into the vehicle to see how the real-world performance will come into play as this analysis is done comparing each unit's own estimation of their accuracy, which could be more or less conservative. The F9R also does not have the capability to use a dual antenna setup and could be a limiting factor in a deployment

4.6 Deployment Results

The Phase 2 deployments of the vans were conducted broadly in two steps for each route - map verification and deployment for data collection. During map verification, the system was first driven in shadow mode on the chosen route to generate data and to find inconsistencies in the map. After this initial map verification, the system was engaged into autonomous mode on sections of the route and further errors in maps were identified. In step 2, the main goal was data collection in autonomous mode. This step-by-step approach was adopted for all the 3 routes separately, as the team received each route maps separately.

The deployments were occasionally conducted in shadow mode for two reasons – data collection in manual driving mode or the ADS platform was deemed unsafe due to repeated system faults. During shadow mode deployments, the ADS was not engaged into autonomous mode, but all the sensors' data was recorded. Furthermore, route was planned before driving, and planning and prediction module data was also logged.

Since the team had two identical ADS platforms, it opened an opportunity to collect data from these two simultaneously to give wider object detection area. The intention behind deploying two (or more) vehicles simultaneously is that the data could be used to get better understanding of the traffic situation surrounding the vehicles.

The team identified a few different ways the two vans could be deployed –

1. Map verification – manual, shadow, and autonomous mode
2. Pre-deployment testing
3. Single vehicle - autonomous mode
4. Single vehicle - shadow mode
5. Multiple vehicles - autonomous mode
6. Multiple vehicles - one vehicle in autonomous mode and other in shadow mode

The total number of runs are shown in the figures below indicating the number of runs for different objectives, vehicles, and routes.

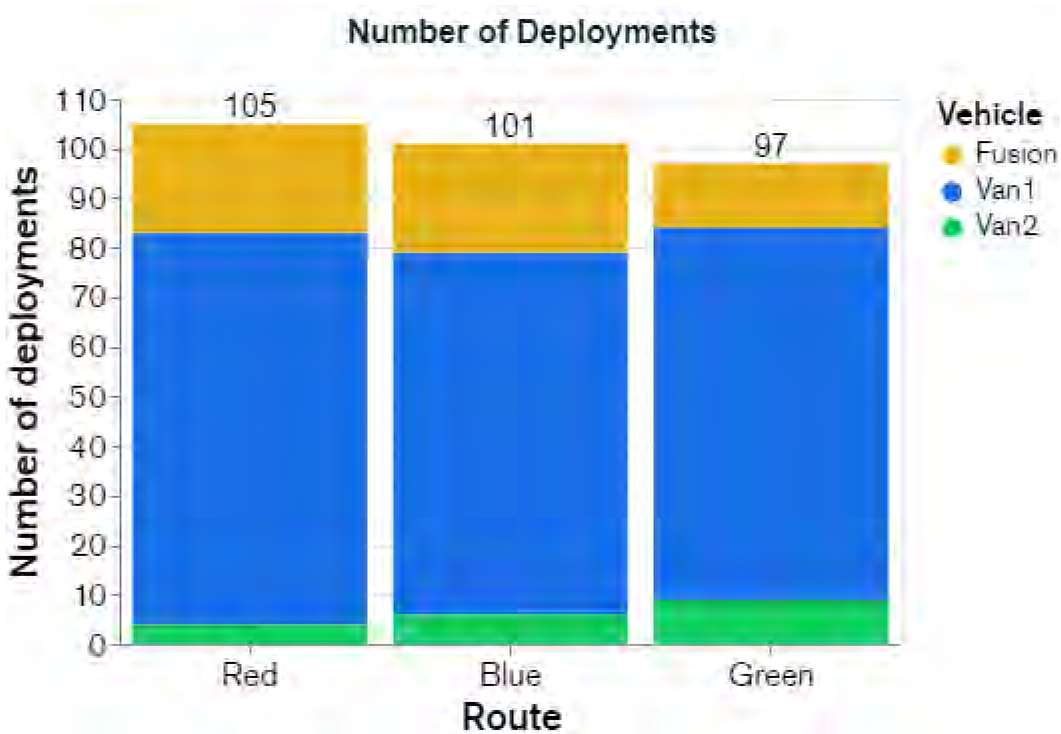

Figure 45: Number of deployments per route for each vehicle

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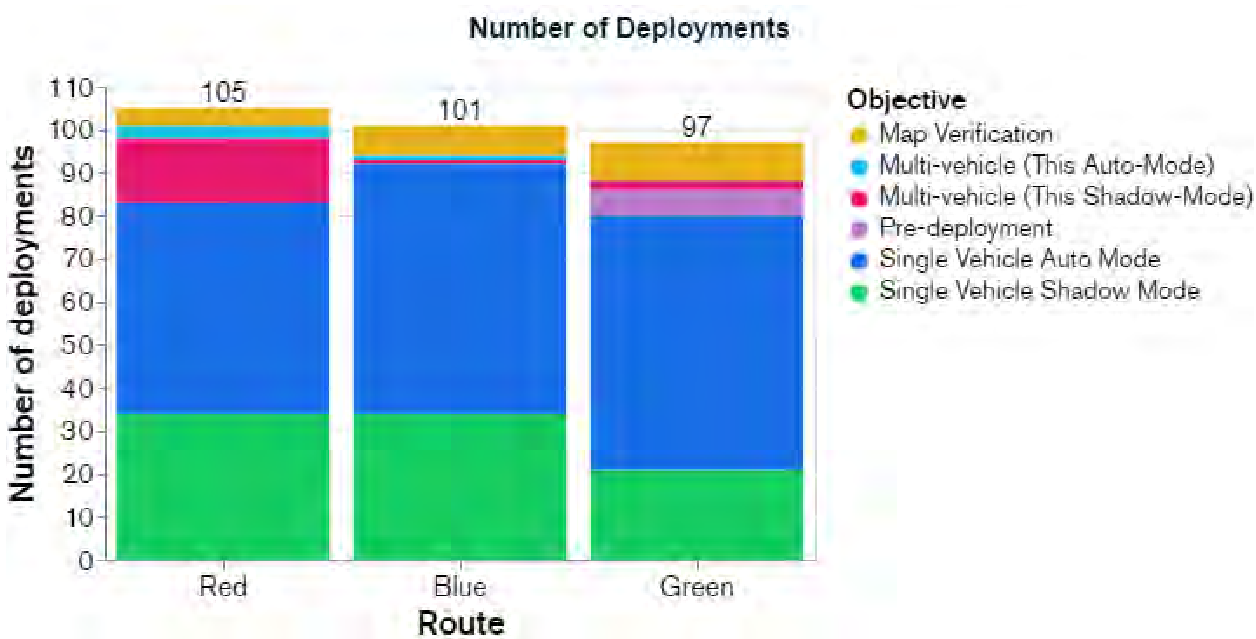

Figure 46: Number of deployments for each route and objectives

In all approximately 17.3TB of data is generated from all the deployments. Table 20 shows the split of data in terms of its storage size generated from each route and from each vehicle. It should be noted that the size of data does not correspond to number of deployments as each route takes different time to complete one run.

Table 20: Data size collected from each route and each TRC vehicle

	Blue	Red	Green
TRC Van1	5.6TB	6TB	2.5TB
TRC Van2	88GB	221GB	237GB
Fusion	1.5TB	800GB	239GB

Figure 47 and Table 21 show summary of the data collected in terms of miles driven. The data is divided into shadow/manual mode and autonomous mode. The manual driven miles include the distance travelled between disengagement and the following engagement. The autonomous driven miles is the actual distance driven in autonomous mode while data was being logged.

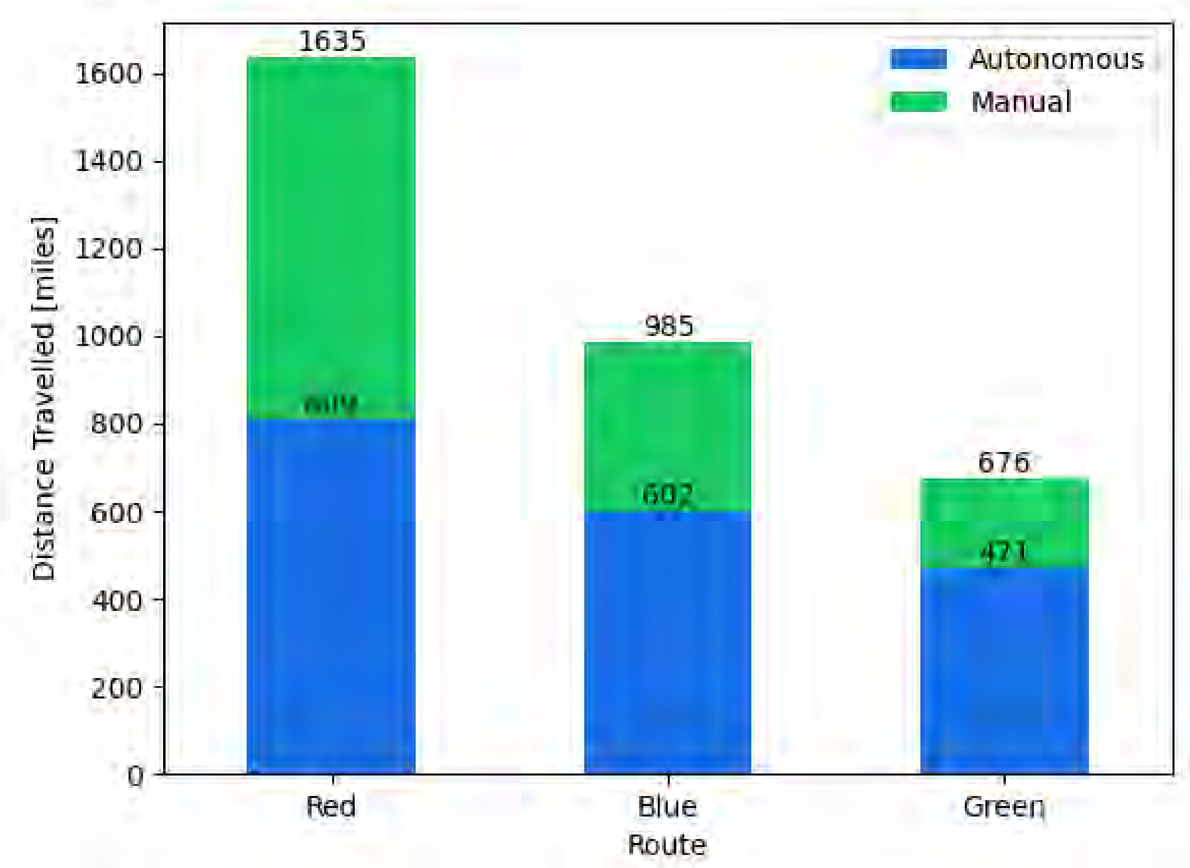

Figure 47: Miles driven in autonomous and manual modes for TRCVan1 and TRCVan2 (i.e. excluding the Ford Fusion deployments).

Table 21: Data generated in terms of miles driven in manual and autonomous mode on the two vans

	Red	**Blue**	**Green**	**Total**
Manual	826	383	205	1414
Autonomous	809	602	471	1882
Total	1635	985	676	3296

4.6.1 Disengagements

To understand the challenges in the automated driving in rural areas, it is of paramount importance to understand the reasons and areas of disengagements. Since the automation stack rarely disengaged on its own, most disengaged were initiated by the driver. Hence, the reasons entered by the deployment team during disengagements would lead to uncovering challenges the automation stack faced. This section provides a summary of disengagement reasons.

On the TRC vans, there were buttons for standard disengagement reasons. These pre-defined reasons were chosen based on pre-deployment data, CE testing results, shadow mode driving, understanding of the routes and team brainstorming. These reasons are listed in Table 22 below. It should be noted that the operators entered disengagement reasons based on their understanding of the situation and what the autonomy stack was doing at the moment. These reasons may not reflect the true reason for the anomalies in the behavior of the stack.

Table 22: Buttons used for disengagement reasons and their explanations.

1	OTHER	Not listed in the 'standard' disengagement reasons. Add note in the message box
2	UNKNOWN	System disengagements
3	OBJ_DETECTION	Failed to detect, track or localize object
4	LOCALIZATION	Veering off-course, localization accuracy indicator flashing warning/error
5	TRAFFIC_LIGHT	Failed to detect correct traffic light
6	INTERSECTION	Failed to detect traffic, stop-sign, failed to stop
7	TRAFFIC_FAULT	Other road actors did not follow standard traffic rules
8	CHILD_PED	Child pedestrian in the vicinity
9	BY_MISTAKE	Accidental disengagements
10	RAILROAD	Crossing railroad. (For safety reasons, the team decided to disengage at railroad crossings)
11	ROUND_ABOUT	Vehicle failed to stay on-course or for safety reasons. The system was not tested for round-abouts, hence round-abouts were out-of-scope
12	INTENTIONAL	ODD outside the scope of the system or due to known limitations of the stack
13	EOR	End of the test
14	NOT_DISENGAGEMENT	Enter notes without disengagement

Discussion on Disengagement Reasons

Figure 48 shows disengagement reasons reported on each route while driving in autonomous mode. It should be noted that single disengagement may have multiple reasons. In Figure 48 one disengagement with multiple reason is counted under each category separately. It can be seen that localization and object detection were the most common reasons for disengagements. Localization disengagement is typically recorded if the vehicle is not capable of staying in the center of the lane. Most often the localization disengagements resulted due to loss of accurate localization. It was observed that Red route has most hills, ravines and narrow curved road. Also cellular network coverage is poor in some sections on Red route. It can be speculated that this resulted into more localization disengagements on Red route as compared to Blue and Green routes. On the other hand, Blue route reported more object detection related disengagements. We believe this is due to the fact that Blue route passes through downtown of Athens and other areas in the town with higher pedestrian and vehicle traffic as compared to the other routes.

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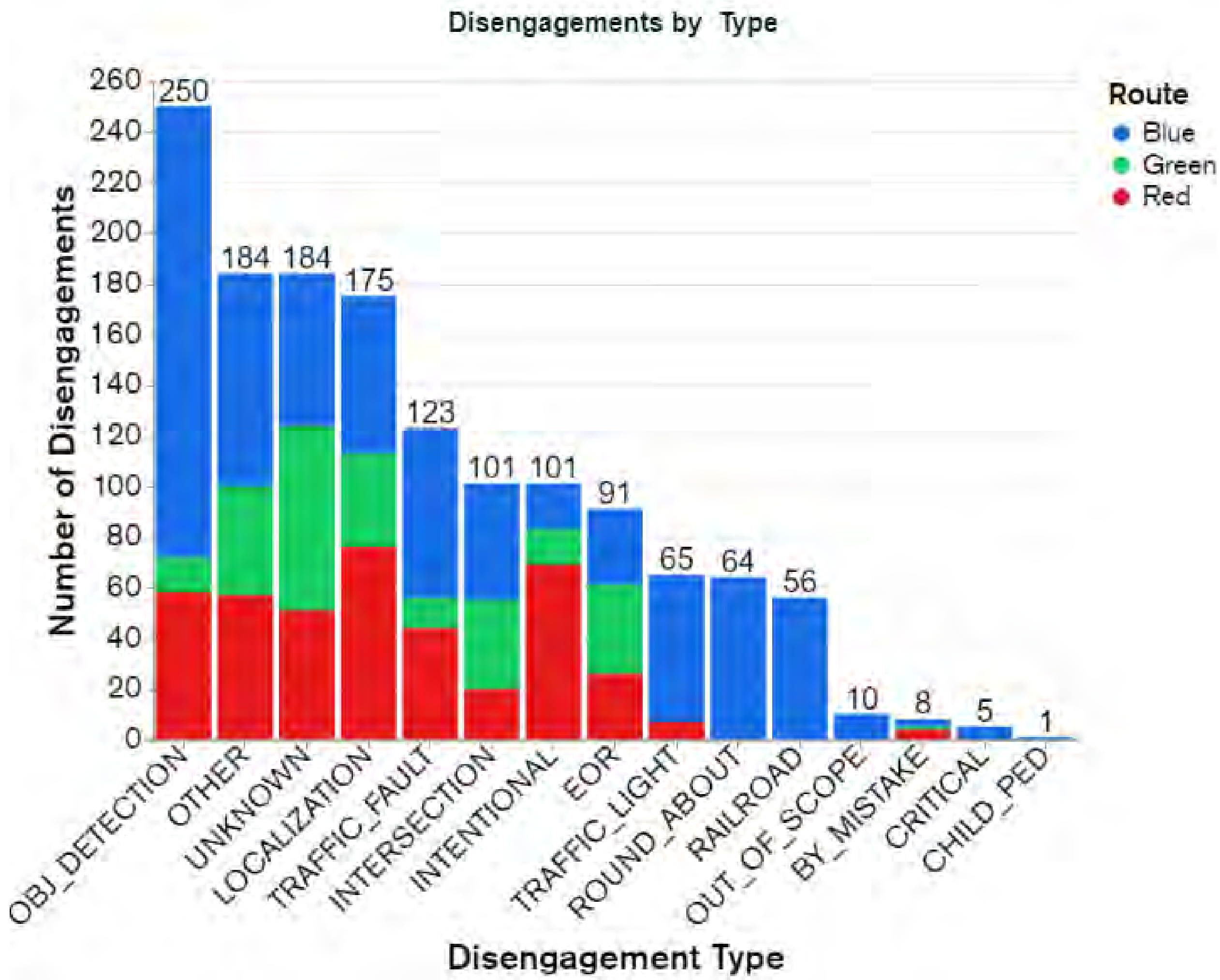

Figure 48: Disengagement reasons by route

The "other" and "unknown" reasons are the next two most common disengagement reasons. Unknown is most-often selected when the autonomy stack disengages on its own for no apparent clear reason. For most of these disengagements, the operators entered reasons for disengagement as a text entry. The team manually evaluated these text entries and re-assigned new reasons. Figure 49 shows the number of disengagements for each of the new category based on the text entries. The disengagements due to system fault are mostly due to failure to re-engage after a disengagement. The team believes that Apollo takes some time to be ready for engagement into autonomous mode after a disengagement. If the driver tries to engage after a disengagement and certain conditions are not met, the autonomy stack does not allow engagement but this is counted as a "disengagement". A new category called "control" was introduced to reflect disengagements specifically due to steering and/or propulsion anomalies. Control related disengagements are mostly when localization was not an issue, but the vehicle could not stay on-course or had jerky longitudinal motion. Occasionally the steering control

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made the vehicle take wider turns at intersections than a human driver would have, and in these cases the disengagement was attributed to control issues.

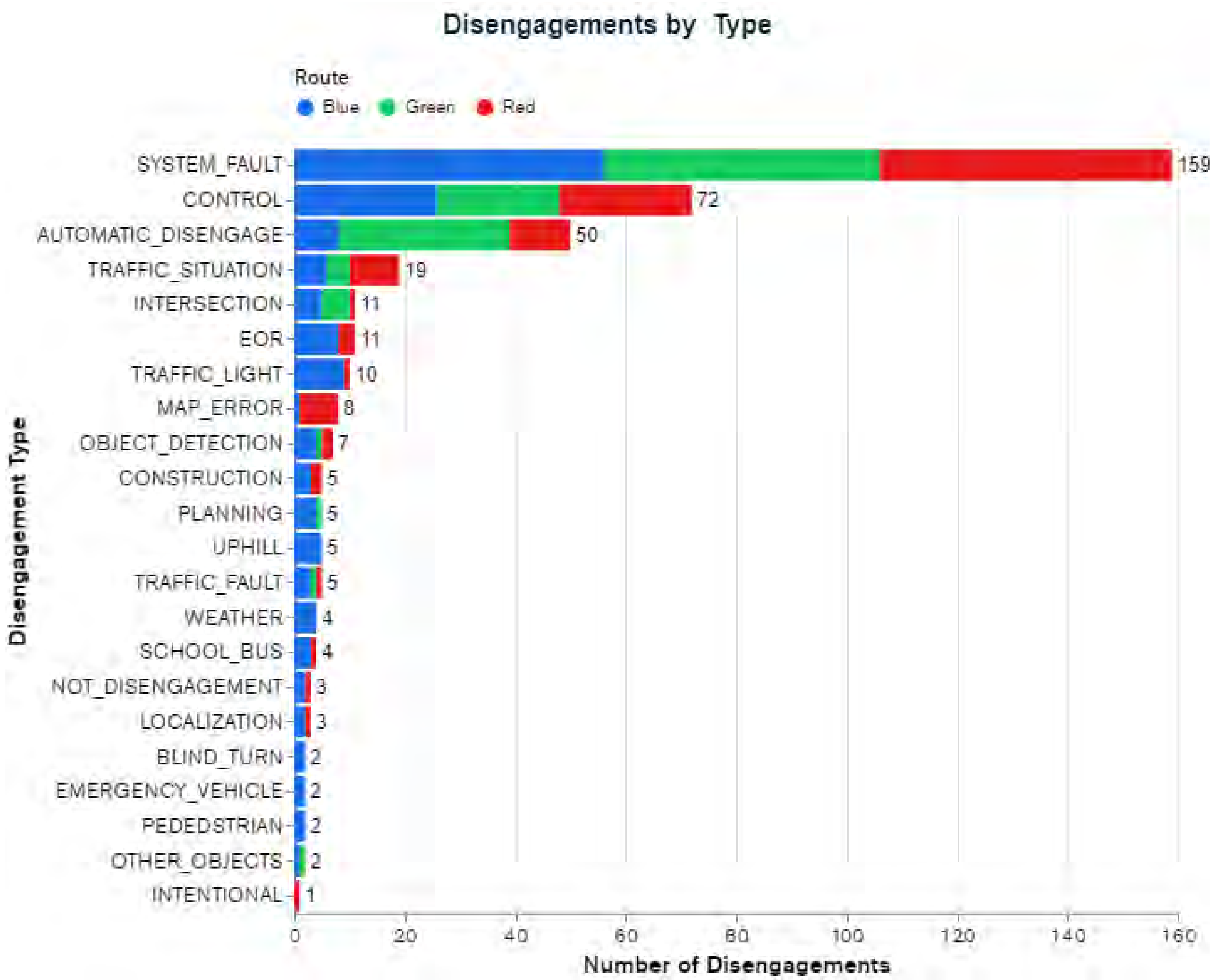

Figure 49: Disengagement reasons from text entries for "OTHER" and "UNKNOWN" disengagement reasons.

To assess the safety or readiness of the autonomy stack on rural roads we compute the number of times the driver had to disengage during autonomous driving. Table 23 shows the number of disengagements per 10 miles of autonomous driving.

Table 23: Number of Disengagements per 10 miles of autonomous driving.

Route	**Blue**	**Green**	**Red**
CRITICAL	0.08	0.00	0.00
INTERSECTION	0.76	0.74	0.25
LOCALIZATION	1.03	0.79	0.94
OBJ_DETECTION	2.96	0.30	0.72

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Route	**Blue**	**Green**	**Red**
OTHER	1.40	0.91	0.70
OUT_OF_SCOPE	0.17	0.00	0.00
TRAFFIC_FAULT	1.11	0.25	0.54
TRAFFIC_LIGHT	0.96	0.00	0.09
UNKNOWN	1.00	1.55	0.63
TOTAL	9.47	4.54	3.87

Furthermore, to understand if disengagements are related to location on the map, the TRC team plotted disengagement reasons on the map.

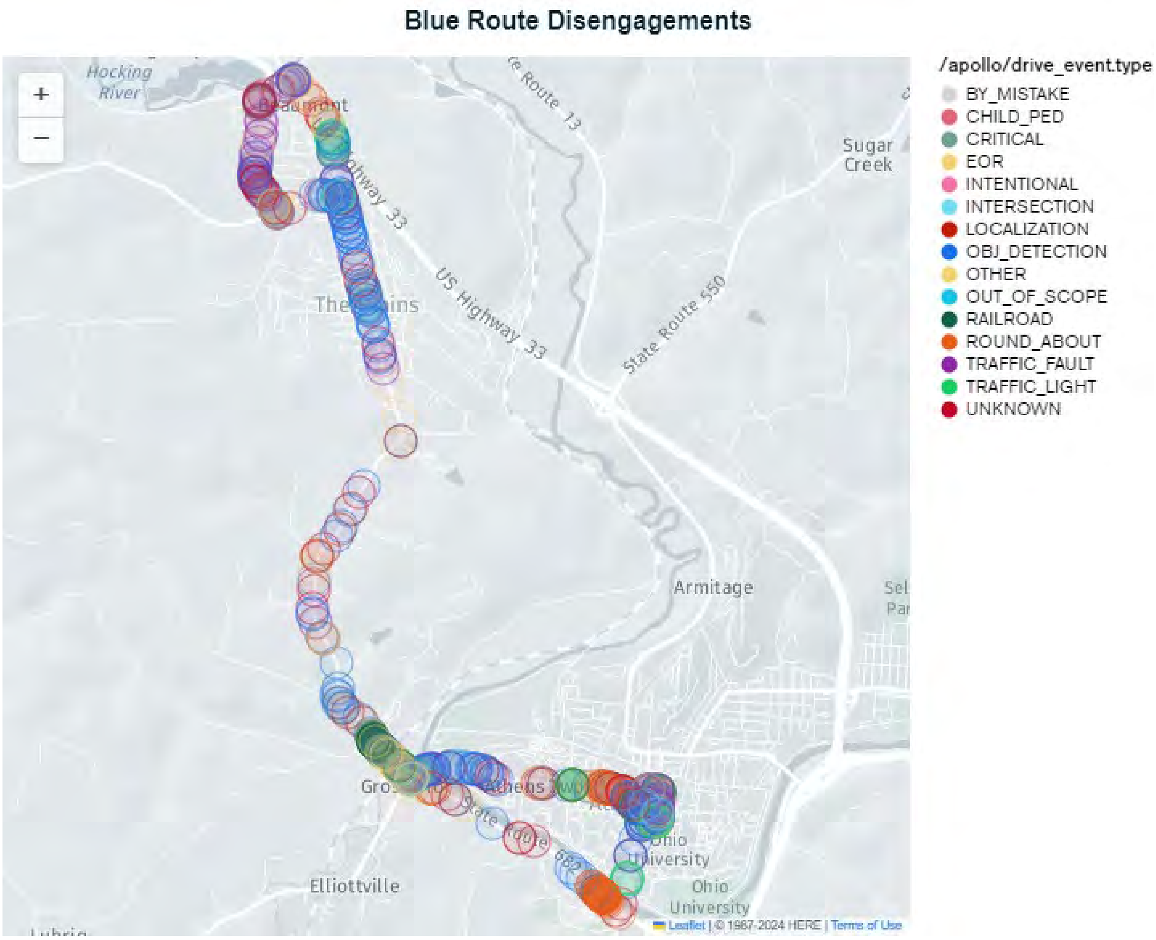

Figure 50: Disengagement reasons on blue route.

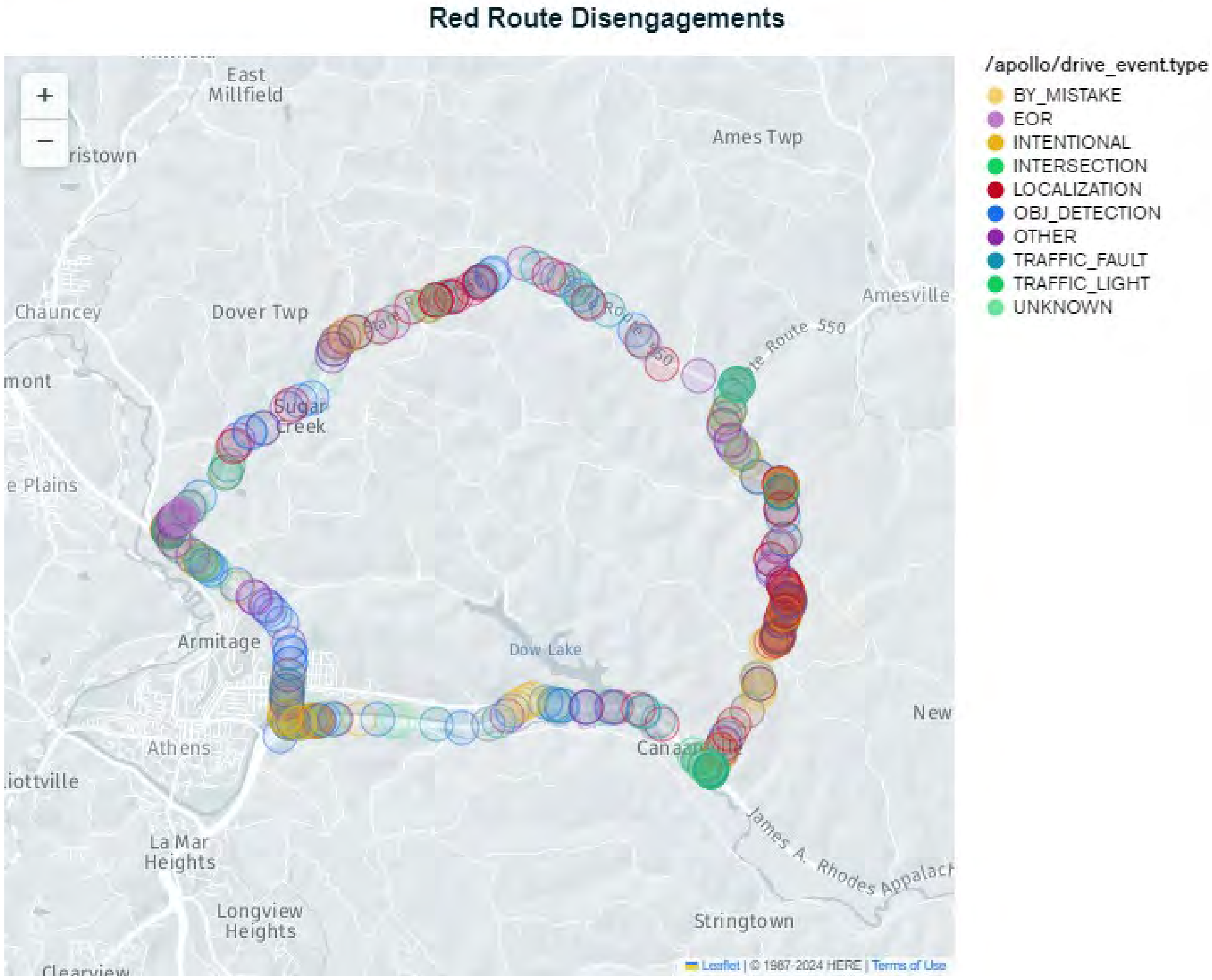

Figure 51: Disengagement reasons on Red route

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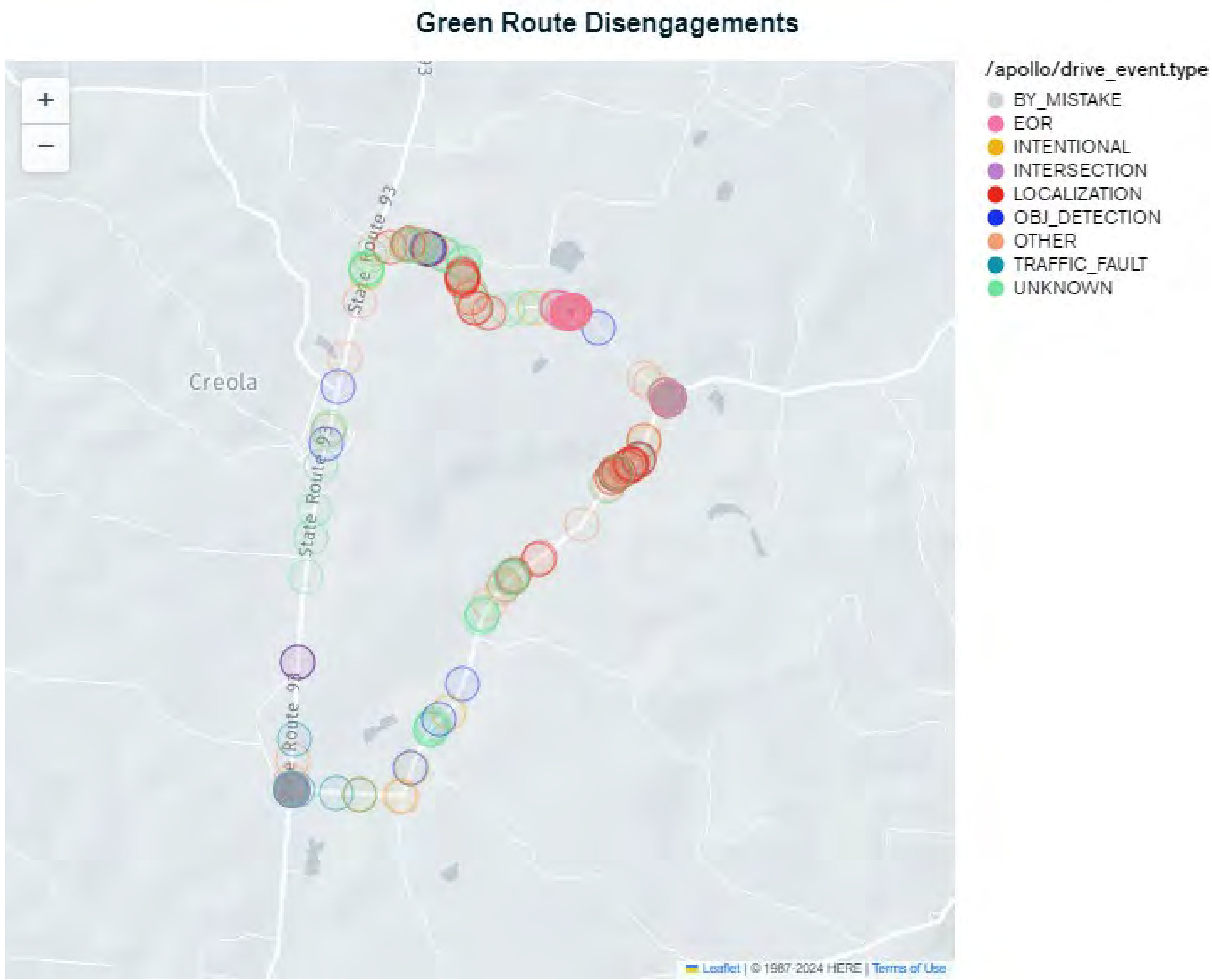

Figure 52: Disengagement reasons on Green route

5 Data Mining with Youngstown State University (YSU)

The main goal of this partnership with YSU was to get a head-start on post-deployment data analysis. The YSU team workstream worked with the datasets that were collected to train AI/ML models on points along the data collection routes where the vehicles did not perform as expected. Then this team discussed with the experts from TRC and DriveOhio to identify potentially challenging areas along predetermined routes where the vehicles had non-ideal performance. Further, this team will analyze the resulting data to illustrate what combinations of environmental (or other) characteristics pose an increased challenge to the autonomous technologies in the rural environment.

The YSU team consisted of graduate and undergraduate students, a graduate student teaching assistant and Prof Jay Kerns as advisor. The team had advisors from TRC and DriveOhio to guide along the way. In the autumn semester of 2023, the team was tasked with understanding the data set, and identifying other sources of data to support the collected data. The students were given access to the DynamoDB dataset prepared using sample runs, and AWS workstations were provided to each student for easy access to the S3 bucket and the dataset. The students developed familiarity with various tools including MongoDB/DynamoDB, AWS, different python libraries, and NoSQL. The team also learned the use of high-definition vector maps and google maps as necessary. They further leveraged pymongo and boto3 python libraries to query and search necessary data from the database.

The team decided to explore if local weather has any impact on the ADS performance. However, precise weather information including cloudiness, temperature and precipitation was not recorded in the deployment data. Hence, the team used National Weather Service (NWS) historic data to obtain this information for the time and place of the deployment. The data needed cleaning, arranging and filtering. A sample queried data from NWS is shown in Figure 53.

id	geometry.c...	properties.e...	properties.el...	properties.ti...	properties.t...	propert
https://api.weather.	[-83.01, 39.43]	wmoUnit:m	221	2023-10-31T12:15:00	Cloudy	v
https://api.weather.	[-82.23, 39.21]	wmoUnit:m	234	2023-10-31T12:15:00	Cloudy	v
https://api.weather.	[-82.4599999, 40.02]	wmoUnit:m	269	2023-10-31T12:05:00	Fog/Mist	v
https://api.weather.	[-82.73, 38.54]	wmoUnit:m	166	2023-10-31T11:56:00	Cloudy	v
https://api.weather.	[-81.58, 39.9799999]	wmoUnit:m	244	2023-10-31T11:55:00	Clear	v
https://api.weather.	[-83.01, 39.43]	wmoUnit:m	221	2023-10-31T11:55:00	Cloudy	v
https://api.weather.	[-82.23, 39.21]	wmoUnit:m	234	2023-10-31T11:55:00	Cloudy	v
https://api.weather.	[-81.59, 38.36]	wmoUnit:m	299	2023-10-31T11:54:00	Fog/Mist	v
https://api.weather.	[-82.4599999, 40.02]	wmoUnit:m	269	2023-10-31T11:54:00	Clear	v
https://api.weather.	[-82.66, 39.76]	wmoUnit:m	265	2023-10-31T11:53:00	Mostly Cloudy	v
https://api.weather.	[-81.43, 39.35]	wmoUnit:m	262	2023-10-31T11:53:00	Fog	v
https://api.weather.	[-82.88, 40]	wmoUnit:m	249	2023-10-31T11:51:00	Mostly Cloudy	v
https://api.weather.	[-82.55, 38.36]	wmoUnit:m	255	2023-10-31T11:51:00	Cloudy	v

Figure 53: Weather data from different stations queried from NWS database

However, it was found that this dataset was only available for 7 days and past data was removed from the database. For further work, weather related data reported by the drivers in metadata will be used for local weather-based analysis.

Appendix B3
TRC Passenger Vehicle Controlled Environment Summary

Passenger Vehicle Controlled Environment Summary

Prepared By:

Transportation Research Center, Inc.

Prepared For:

DriveOhio

The Future of Smart Mobility

XX/XX/2022

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List of Acronyms, Abbreviations and Symbols

ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
GPS	Global Positioning System
NHTSA	National Highway Traffic Safety Administration
ODD	Operational Design Domain
SV	Subject Vehicle
SAE	Society of Automotive Engineers
SSV	Strikeable Surrogate Vehicle

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1 Introduction

The Transportation Research Center Inc. (TRC) has completed the Controlled Environment Testing for the Automated Driving Systems (ADS) Demonstration Grant awarded to DriveOhio-led team by The U.S. Department of Transportation (USDOT). The purpose of the project is to evaluate ADS operation in rural areas. A variety of tests were conducted on an ADS-equipped passenger vehicle in a controlled-environment to help inform the plans for deployments on rural roads and demonstrate safety of the proposed ADS.

This document provides the reader with:

- A brief overview of the ADS system, platform, and the vehicle chosen for the ADS Demonstration Grant.
- The Controlled Environment Testing that was conducted for the chosen ADS vehicles.
- The conclusions of the controlled environment testing.

TRC Inc. has conducted the Controlled Environment Testing at the Transportation Research Center Proving Grounds in East Liberty Ohio, with support from project partners. The results of the Testing and Evaluation informed the ADS Demonstration Grant team of the operational considerations, necessary safety procedures, and readiness for deployments and data collection on rural roads. Furthermore, the requirements of driver training for these specifically tested vehicle/ADS stack were finalized during testing. All of the information derived during the course of Controlled Environment Testing will be used to update the test plans used during deployments on public roads.

2 Controlled Environment Testing Objective

There were two primary objectives of controlled environment testing that was performed by TRC Inc.:

1. System education and prove out
2. System behavior extrapolation

The first objective of controlled environment testing was for the testing and research teams of TRC Inc. to educate themselves on the system that was tested and prove out the operational characteristics being tested. For any ADS system that will eventually be tested on public roads, this includes the following sub-objectives:

- Basic systems functionality training and prove out

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  - TRC Teams must achieve mastery of the system to ensure that tests can be performed safely, reliably, and repeatedly. This means training test teams on the appropriate systems so that they have an understanding of how to operate the vehicles, as well as expected vehicle behavior across all potential scenarios. Systems and personnel are taken through a wide variety of testing scenarios to prove out systems operations and train the personnel on vehicle operations.
- Data recording development and prove out
  - As a requirement of testing, all data acquisition systems (DAQ) must be developed and deployed in a controlled environment to prove out operation prior to on road deployment. All necessary personnel need to be trained on all DAQs prior to on road testing. This includes the prove-out of the entire data transmission pipeline up to the point of data storage pending data processing.
  - The ADS vehicle used Robot Operating System (ROS) as the main backbone for transmission of data between the sensors, computer, and actuation. This served as the main DAQ, as it allowed for a standardized collection of the data, where all the sensor data and control commands were collected in pre-determined messages. These messages were recorded and are able to be converted to other storage mediums in the future.
- Limit systems operations
  - It is necessary for test teams to test systems at operational limits. While nearly all public road testing does not occur at operational limits, operational limits, such as a maximum speed of 35mph, can sometimes be reached during road deployments. As a result, it is necessary for test team members to understand where the operational limits are and how the vehicle responds prior to operational limits, once operational limits are reached, and as operational limits are exceeded. This is to ensure the safety of test teams, equipment, and potential pedestrians.

An inherent limitation of any controlled environment testing is an understanding that only a small portion of the potential operational scenarios will be covered during controlled environment testing. This limitation necessitates that the subset of tests covered during controlled environment testing allow for the extrapolation of vehicle behavior to all scenarios that might be encountered on roadways. This is the second objective to be accomplished, taking the demonstrated behavior seen during the testing and extrapolating to potential failure modes that could be seen on roads. This extrapolation is primarily completed through root cause analyses, where the fundamental failure seen during failed tests is determined. With the failure cause properly determined, it is possible to extrapolate where additional failures might occur for the same reason.

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3 Background

3.1 An Overview of the ADS System, Platform, and Vehicles

The CE test focused on single vehicle automation capabilities of the ADS system. The following sections cover the ADS software, sensors, vehicle models, and test categories that are part of the controlled environment testing program. The ADS platform deployed for this phase of testing was a prototype Society of Automotive Engineers (SAE) L3 conditional automation system.

The ADS vehicle used for the testing program is outfitted with a Dataspeed drive-by-wire kit and a suite of sensors provided by AutonomoStuff. They relied on a version of Autoware that has been sold and configured by AutonomouStuff. Autoware is an open-source software package for automated driving systems. Autoware provides a set of software subsystems such as localization, planning, perception, and control that make up the automation stack, as shown in Figure 1. Figure 2 shows a view of the software stacks localization and planner visualizer. The software is built on the popular ROS v1 framework.

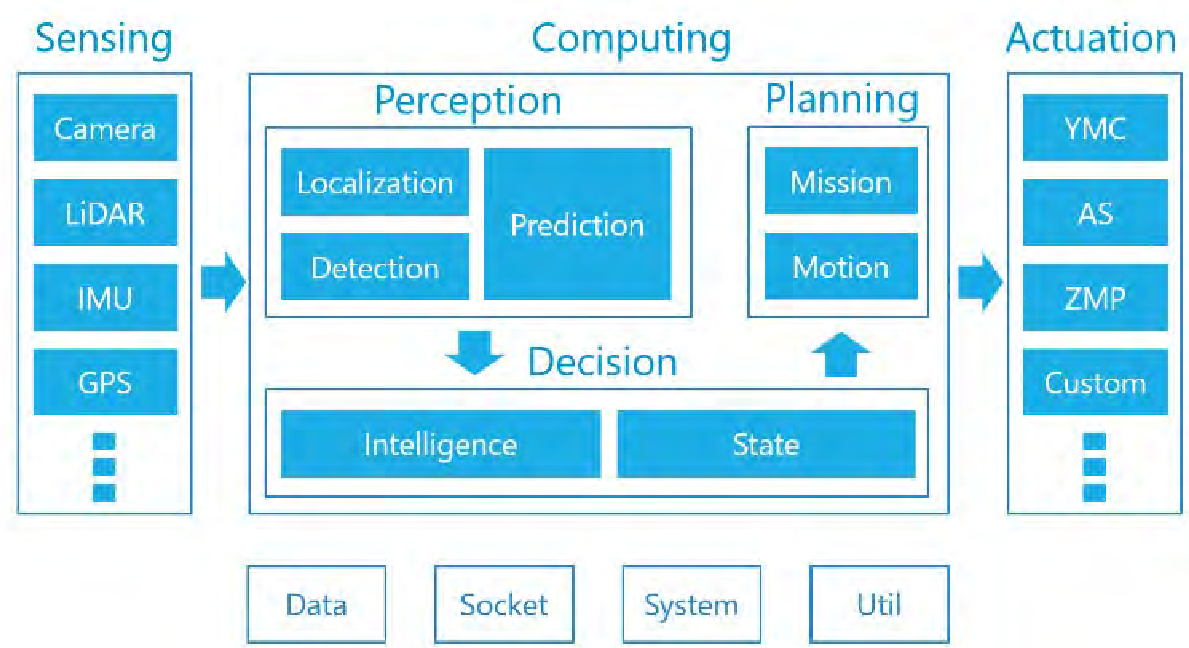

Figure 1. System diagram of Autoware and the different sub-systems.

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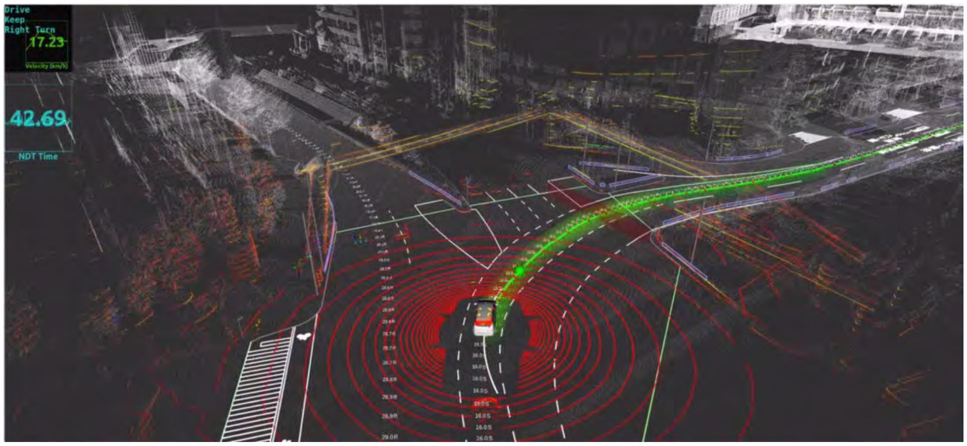

Figure 2. View of Autoware localization visualizer with planned path.

3.2 ADS Sensors Overview

The vehicle is equipped with numerous sensors that are required by Autoware such as LIDAR, GNSS/INS sensor, and cameras. The LIDAR has a 360° view that technically reaches 250 m. However, it more practically reached 80 m. The camera has a forward view only with a range of 50 m. There are also several radars on the vehicle; but they are not employed in ADS operations.

3.3 Alignment with Passenger Vehicle ConOps

The Controlled Environment Test Plan used information presented in the Passenger Vehicle Concept of Operations (ConOps) to build out a test plan based on outlined user needs. The project team's knowledge of the ADS stack (Autoware) and ADS vehicle platform was also used to refine user expectations, when necessary. This test plan excluded test scenarios in select cases where the ConOps documents a user need (ex. co-operative lane change), but the documentation specified the ADS stack could not satisfy. In the future, should that capability be developed or a different software stack be chosen that has that capability, controlled environment testing will need to occur again.

The Controlled Environment Test Plan focusses on the following use cases and operational scenarios listed in the Passenger Vehicle ConOps:

- Use Case 1, Scenario 1 (UC1-S1) – Single Vehicle Automated Driving – ADS
- Use Case 4, Scenario 1 (UC4-S1) – Intersection Navigation
- Use Case 4, Scenario 2 (UC4-S2) – Intersection Navigation with SPaT and MAP
    - This testing wasn't conducted as the ADS stack did not have the capability to use SPaT or MAP messages.

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3.4 Controlled Environment Test Scheme

The Controlled Environment Testing took a phased and categorical approach towards developing an understanding of the ADS-equipped vehicle's capabilities to operate safely on public roads. The scheme was structured to expose the ADS-equipped vehicle to progressively complex situations, test the ADS's response, and inform the safety operator of expected system behavior. This evaluation assessed knowledge gaps, functionality gaps, and increased the safety operator's confidence prior to Deployment One in central Ohio. Figure 3 shows an overview of the testing scheme.

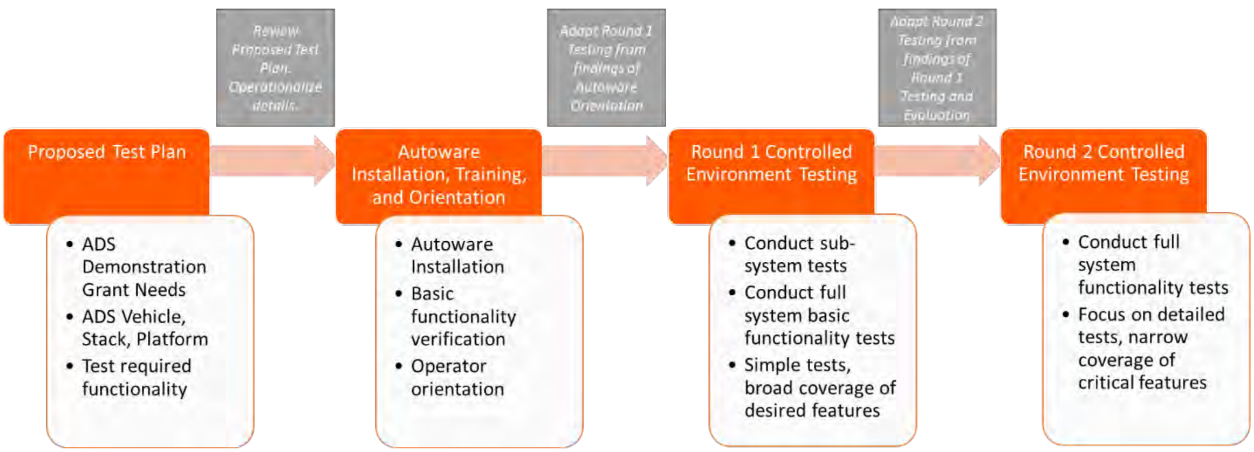

Figure 3. Flow chart of test plan development and implementation.

The Controlled Environment Testing followed the training and orientation period of Autoware by AutonomouStuff. The testing was divided into two rounds spread over several calendar months. The first round of testing consisted of basic systems tests intended to test functionality and performance of ADS subsystems over a broad set of features. The second round of testing exposed the ADS to situations with increased complexity within a chosen subset of functionality. The two rounds were built off each other by increasing the level of situation complexity, difficulty for the automation stack, difficulty of test preparation, and evaluation facets such as, level of acceptance thresholds, and expectations of ADS system's behavior. The increased complexity of the situations was also designed in such a way that a human driver would also be increasingly taxed by the complexity.

While the level of complexity and detail between the two rounds is different, each round of testing still assessed the ADS-equipped vehicle's functionality and performance by:

- Functionality testing of various individual ADS subsystems.
- ADS performance under targeted road-user scenarios.

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The two rounds of tests presented in Section 4 incorporated many test scenarios of varying complexity designed to cover a wide range of ADS capabilities, individually as well as in combination. All testing programs evolve and expand throughout the course of the project as additional information is learned. This project has and will continue to follow that trend.

4 Testing Round 1 – Fundamentals and Subsystems Testing

4.1 Objectives

The focus of Round 1 of the Controlled Environment Testing was to subject the ADS-equipped vehicle to a broad spectrum of sub-system and basic full-system functionality tests, covering a wide array of desired features. These tests were designed to answer questions such as:

- Can the vehicle power-up individual sub-systems such as control, localization, or object perception?
- Can the vehicle route plan consistently and reliably?

The focus was on understanding the reliability of the features available on the ADS-equipped vehicle and ensuring a safe deployment on public roads was possible. Outcomes from Round 1 of testing informed modification to the subsequent portions of this testing plan. The following subsections outline the categories of tests that were performed.

4.1.1 Initialization Checks

For Round 1 tests, the goal was to understand the ADS-equipped vehicle's initialization and launch procedures for subsystems as well as the complete system. The use of an open-source ROS based automation stack lent itself well to executing a phased launch of ADS's individual modules such as, localization, object detection, etc. While developing an understanding of the procedures is important, a subjective assessment was made on their ease-of-use, configurability, and the ADS-equipped vehicle's ability to repeatedly initialize under tested conditions.

4.1.2 Perception

An ADS-equipped vehicle's ability to detect and respond to objects encountered along the roadway is an important facet of ensuring safe driving. In this category of tests, the ADS-equipped vehicle was exposed to a wide variety of objects such as passenger vehicles, VRUs, and limited roadside debris to note its detection and response. The objects were classified per industry recognized frameworks such as the SAE Automated Vehicle Safety Consortium Best Practice

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(2020)[1], NHTSA[2] (2018), or TRC Inc.'s research published for research clients. The detection and response of the ADS-equipped vehicle was tested under broad categories of objects, including but not limited to:

- Cars, VRUs, boxes/facades, relevant roadside debris
- Traffic Control Devices – Lights, Stop Signs, Other Signs

4.1.3 Localization

Location awareness is a key aspect of, and is indispensable to, accurate operation of an ADS system. Localization tests were largely performed by manually driving the vehicle at the test track and comparing the reported vehicle location (position, orientation, and velocity) against ground truth sensors. Features listed below were assessed:

- Initialization, accuracy, failure rate, recovery
- Vehicle pose
- Vehicle velocity

4.1.4 Path Planning

The ability of an ADS-equipped vehicle to plan routes, using the information available to it, is an important part of its feature set. An ADS stack can decide its route-plan based on information contained solely in High Definition (HD) Maps or through real-time information that is available. Other ADS stacks may have the ability to accommodate information obtained dynamically when driving the route such as from SPaT or determine lane driveability to re-plan and reach target destination. A test of an ADS stack's ability to route plan included an assessment of features such as:

- Route plan "soundness"
- Interface and ergonomics

4.1.5 Motion Control

These tests were geared toward performance evaluation of the low-level control system that actuates the vehicle. This includes vehicle launch at the beginning of the route, stopping the vehicle at the end of the route, and longitudinal and lateral control during ADS operation.

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[1] Society of Automotive Engineers. (2020). *AVSC Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon* (AVSC00002202004).
https://www.sae.org/standards/content/avsc00002202004/

[2] Thorn E., Kimmel S. and Chaka M., "A Framework for Automated Driving Systems Testable Cases and Scenarios," U.S. Department of Transportation National Highway Traffic Safety Administration, Washington, D.C., 2018

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4.2 List of Tests

This section enumerates and summarizes the tests completed for the first round of testing. The tests completed potentially cover multiple objectives for the same test, and, thus, fall across different categories.

4.2.1 ADS Sub-system and System Initialization

The first tests completed were intended to allow the TRC Team to assess ADS startup and basis sub-system/system initialization. The tests were meant to demonstrate the basic safety functionality of the ADS software. Of specific interest was the system's ability to engage and disengage while in various traffic streams. These first tests demonstrated various deficiencies in the ADS software that had to be corrected prior to any on road deployments. This document will briefly touch on the solutions to discovered deficiencies. Below is a summary of the initial questions that the TRC Team sought and the answers resulting from the tests.

- How does the ADS stack engage from a standstill, while in motion?
  - The ADS stack will engage from a standstill and when it is currently in motion.
- How does the ADS stack engage when current vehicle state deviates from prescribed planner state (i.e. the desired location for the vehicle in the planned route)?
  - A certain level of deviation from the prescribed planner state is tolerated where the vehicle will still engage the ADS. However, the TRC Team was unable to fully determine the acceptable envelope that would allow for engagement. The vehicle can engage anywhere along the route, at the very beginning of the route all the way until near the end of the route. This covers engagement in the longitudinal direction. However, there was inconsistent behavior with regards to lateral deviation and rotational deviation and whether the system could still be engaged. There were countless occasions where the stack would not engage on the first try and the team would move the vehicle forward a foot and the vehicle would engage. There were similar experiences with regards to other displacements, where the vehicle just had to be moved slightly to one side or another before the system could be engaged. This led to the conclusion that engagements were relatively easy, but the operators of the vehicle would need to be prepared for multiple attempts to engage the vehicle.
- Will the ADS system disengage if planner state cannot be achieved?
  - The planned route is static and determined once the destination is given (if possible). There was never an instance where the vehicle would engage unless a route plan had been achieved.
- What are the ADS system disengagement criteria?

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- Several disengagement criteria were determined and denoted by the team. These include driver takeover, camera and LIDAR failure (added during testing), GNSS RTK failure (added during testing), and map error (i.e. software stack was not able to resolve the stop line in the map caused erratic behavior from the vehicle and disengagement). However, there were numerous unexpected and unannounced disengagements. When these occurred, the vehicle would begin to coast and drift in the lateral direction until the safety driver took control of the vehicle. The TRC Team was unable to determine why these disengagements occurred.

- What methods can a manual driver use to disengage the system?
    - The driver can disengage the ADS by either taking control of the pedals or steering wheel, the manual request overrides the ADS, or the driver can disengage the system by requesting it through the software terminal.
- What are the means that the ADS system uses to relay operational state to the driver?
    - The system uses a combination of visual cues from the manual software terminal in RVIZ and audio cues. However, as previously stated, there were instances that have been seen during vehicle operation, specifically around disengagements where the vehicle did not provide audio alerts of disengagement. TRC has added an additional layer of visual cues through a custom software terminal meant to aid the safety driver in understanding the current vehicle state.
        - ADS operator's RVIZ screen and a hardwired switch (TRC added during testing) had color coded light to provide ADS status. Green - ADS is ready to be engaged, Blue – ADS is engaged, and Yellow – ADS is not available. When driver disengages, chime is produced from the Dataspeed system.

The initial tests conducted were intended to assess the ADS's ability to engage under different circumstances and understand vehicle disengagements. The TRC Team discovered that there was a need for additional safety checks in the system when the stack was able to engage without the LIDAR being powered up. Further tests demonstrated that nearly all ADS components could be non-operational and the driver could still engage the ADS. The TRC Team added custom software into the ADS stack that would ensure basic safety checks were performed prior to ADS engagement and throughout ADS operation to ensure that all sensors were operational prior to a vehicle engage. The same software would also disengage the vehicle should a sensor (LIDAR, GNSS/INS sensor, and cameras) data stop being received during operation.

The engagement and disengagement tests also revealed numerous inconsistencies regarding the start and end of ADS operation. Overall, the system engaged with the safety driver momentarily releasing the vehicle controls and the technical operator engaging the ADS through a software switch. However, there were numerous instances where the ADS would not engage on the first attempt. This occurred in both static and dynamic starts. The technical operator would need to

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attempt engagement numerous times with no change in vehicle state or minor changes in vehicle state prior to the system engaging. TRC was unable to provide a conclusive reason why some ADS engagements worked and other didn't. Disengagements followed a similar pattern where the majority of disengagements provided the driver appropriate warning and met TRC's expectations. However, there were several disengagements where the ADS disengaged without notifying the vehicle occupants that the system had disengaged. This led to the vehicle beginning to drift in lane and coast down. TRC Inc. was unable to determine why these disengagements occurred or why there was no alert that the disengagement had occurred. As a countermeasure and to improve operator awareness TRC Inc. implemented a driver aid that provides information to the safety driver allowing them to monitor the engagement/disengagement state of the vehicle at a glance.

4.2.2 Localization Accuracy

Location accuracy was tested throughout Round 1 and 2 of testing as the vehicle always had the NovAtel and Oxford GPS with RTK corrections in the vehicle. For AutonomouStuff variant of Autoware, localization is solely a function of the Novatel GPS with RTK corrections. This combined sensor is used to determine the coordinates of the vehicle which are used in combination with HD maps to determine location relative to roadway features, such as lanes. During all runs, the ADS GPS unit was compared to an Oxford GNSS that TRC put into the vehicle. All testing throughout the controlled environment testing showed that the localization method of the ADS provided sufficient localization to keep the vehicle in the desired lane. However, in a single test during Round 1 there was an offset in the recorded coordinates versus the actual vehicle position. The vehicle was offset ~1.8m laterally to the passenger side of the vehicle. This resulted in the vehicle reporting that it was operating in the middle of the intended lane of travel, when in reality the vehicle was operating on a divider line between two lanes. After the ADS was restarted, the issue went away. This has only occurred a single time and TRC has been unable to replicate this observed behavior since that test. Another similar offset occurred due to an error in the HD map and was able to be resolved. =

4.2.3 Waypoint Following

The TRC Team ran the vehicle through a variety of different waypoint paths throughout controlled environment testing, focused on understanding the vehicle's localization and path following. For these tests, a safety driver first drove various routes in the high speed course and the urban network to record the waypoint path. The ADS then executed those routes under a variety of different conditions with altered adjacent vehicles, roadway objects, and different traffic light patterns. This was specifically looking at waypoint following and was detached from lane following or anything using the HD map. However, the vehicle did have the capability of recognizing traffic signs and lights from the HD map file, but this was not proven to be consistent.

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The vehicle was accurately able to replicate the path and speed of the waypoint recording. However, there were two particular safety issues discovered with waypoint, including missing traffic signs and lights and following path regardless of lane lines and adjacent traffic. For an example of the latter, if the way points cross a lane line, the vehicle will follow even if there is an adjacent vehicle.

As is seen in Figure 4 below, the performance of the lateral and longitudinal controller is evaluated under the waypoint following test. A path and speed are recorded by the safety driver as shown on the map. Path includes straight line, left, and right hand turns. Speeds are varied from 0 to 35mph. The Lateral Error plot indicates that nominally the error in path following is ~0.2m. The Speed following performance of the controller is good, as the actual speeds closely match-up to the demand set by the waypoint following algorithm. The result is further queried at three time instances (L1,L2,L3), which are cross referenced on the map as well as speed and lateral error result plots. Investigation reveals that lateral errors of the magnitude of 0.4m to 0.6m may be found when navigating sharp turns as seen at locations L2 and L3. This is sufficient to keep the vehicle in a desired path, but brings the vehicle close to the edge of what should be expected behavior.

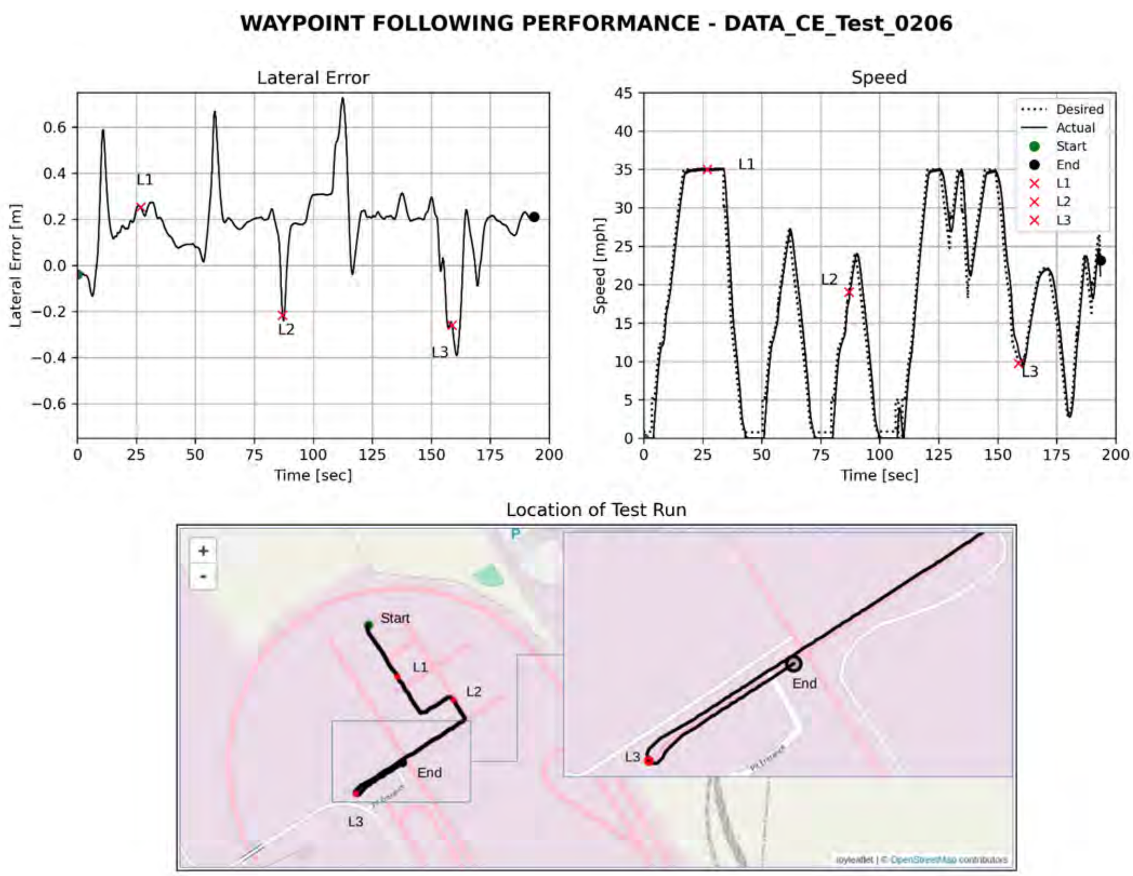

Figure 4. Waypoint Performance, Analysis 1.

Another test run is shown in Figure 5. A path and speed are recorded by the safety driver as shown on the map. Path includes a U-Turn in the turnaround bulb, straight line driving, and right hand turn. Speeds are varied from 0 to 35mph. The Lateral Error plot indicates that nominally the error in path following is ~0.3m. The Speed following performance of the controller is good, as the actual speeds closely match-up to the demand set by the waypoint following algorithm. The result is further queried at four instances (L1,L2,L3,L4), which are cross referenced on the map as well as speed and lateral error result plots. Investigation reveals that higher lateral errors may be found when navigating sharp turns at higher speeds than normal. In this case, the 1.5m deviation is enough to bring the vehicle out of a desired lane, however was in a section of the course where there were no lane lines to verify this visually and in a turning maneuver not common on public roads.

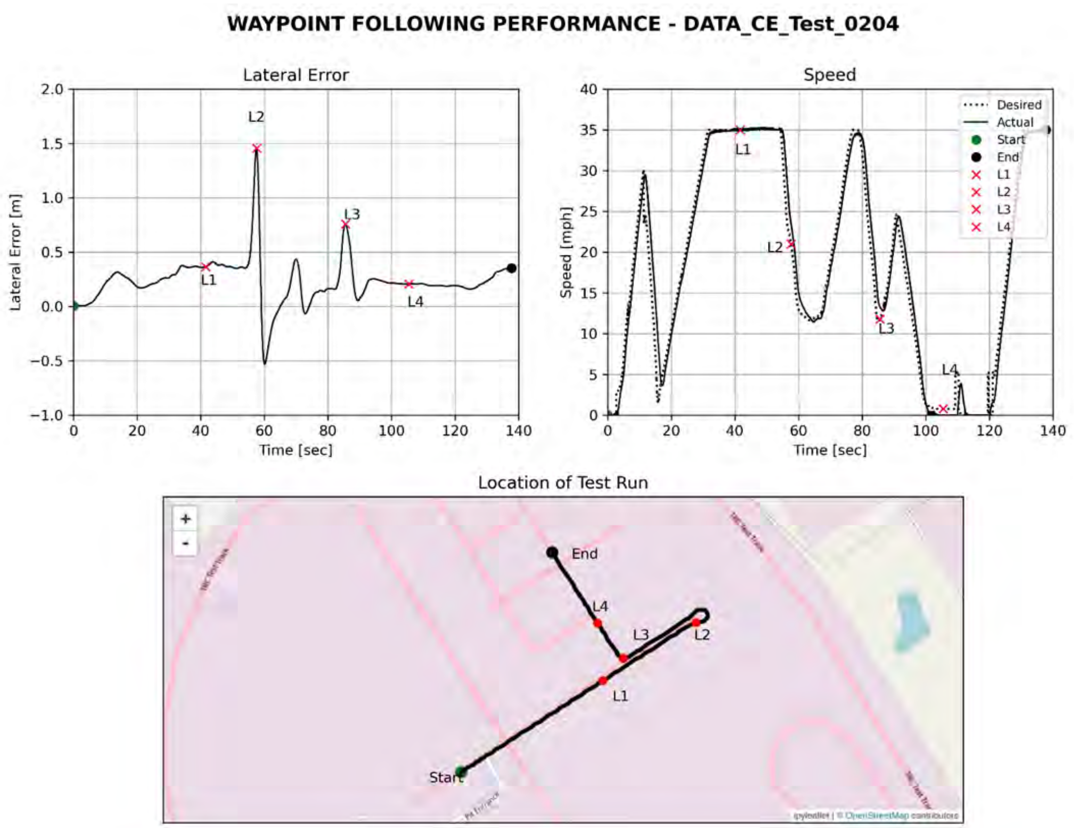

Figure 5. Waypoint Performance, Analysis 2.

The following is a summary of the original questions that the team sought to answer during waypoint following testing.

- What are the control limitations for way point following? (Speeds, lat/long accelerations, etc.)

    - Vehicle motion control limitations are defined in a separate parameter file and the vehicle was observed to follow the user defined values.
- Will the vehicle respond to obstacles while way point following?
    - Yes, the ADS will respond to obstacles assuming that they are in the immediate path of the vehicle and have a sufficient LIDAR signature as defined by the parameter file. The vehicle will not respond to adjacent vehicles that are coming up on the vehicle path or conflicts in the time horizon.
- Will the vehicle respond to traffic control features while way point following?
    - The vehicle will attempt to respond to traffic control features. However, the CE test found numerous deficiencies of the system. There were repeatable instances where the vehicle would stop at traffic control features as expected, proceed into the intersection, but then initiate the traffic control stop function again in the middle of the intersection. In other instances, the ADS would not stop at traffic control devices at all during waypoint following.

4.2.4 Route Planner

The route planner appeared to find the shortest feasible path between two points, and the planner will not change lanes to accomplish the path. This was demonstrated during tests when the vehicle was given simple straight line paths on a multi-lane road and objects were placed in the lane of travel. The vehicle responded to the object and stopped in the lane of travel. The vehicle would not change lanes to move around the object even though adjacent lanes were open and legal lane changes were available. Once the object was removed from the path of the vehicle, the ADS resumed operation and proceeded to the end of the route. Additionally, at the end of planned routes, the vehicle would go into a stopping procedure, which is set in the parameter file. During this operation, the vehicle ignored normal operation, such as traffic rules, and it was imperative that the driver take control. Below is a list of the original objectives that TRC Inc. sought to understand during route planning testing.

- Will the vehicle plan a route while in motion?
    - The vehicle can plan a route while moving at low speeds, approximately 15mph or less.
- Does the vehicle need to be at/near the start of the route to engage the vehicle?
    - No, the vehicle can engage at any point along the route as long as it is within a limited envelope around the route.
- Is route planning dynamically updated? If so, what is the update frequency?
    - No, the AutonomouStuff variant of Autoware does not dynamically update.
- What is the objective function used for route planning generation?

- The criterion for route selection was the shortest travel distance along a feasible route, without lane changes.

- If deviations from the planned route occur during operation, what will the system do?
    - The ADS stack did not deviate from the planned route. If there was a detected obstacle within the path, the vehicle came to a stop until the object was no longer in the planned path.

4.2.5 Lane Keeping

Lane keeping tests revealed that there was a chance for errors as demonstrated during controlled environment testing. The ADS stack does not utilize computer vision or any method of real-time detection of lane lines or roadway edges. Lane lines and roadway edges are pre-programmed into the ADS solely through the HD maps. HD maps are required to be generated prior to ADS operation. Lane operation is only maintained through the GPS with RTK corrections in combination to the HD maps. If lane lines differed from the HD maps, such as for construction, the vehicle executed the lane lines in the HD maps regardless of local lines. Furthermore, the system was dependent on a single sensor for localization. Any issues with the GPS or the RTK corrections resulted in an offset in the vehicle operation, but not be known to the vehicle that such an error was present. This occurred only once during testing and is detailed in Section 4.2.2. The following questions were tested during the course of controlled environment testing.

- Does the vehicle detect lane lines?
    - No, there was no detection of lane lines.
- Does the vehicle detect road edge?
    - No, there was no detection of road edge.
- Does the vehicle incorporate these detections into motion control?
    - Not applicable.
- Should lane lines differ from HD maps, which factor is followed?
    - Only HD map lane lines were followed.
- How does lane following operation engage/disengage during dynamic events like turning?
    - After a disengagement occurs, the ADS did not take any effort to ensure a smooth transition to the safety driver. For example, should a disengagement occur during a turn, the vehicle released all vehicle controls in the middle of the turn. The vehicle will begin to straighten out, drift, and coast down.

4.2.6 Detect and Respond to Speed Limit Signs and Stop Signs

As a consequence of no computer vision or utilization of vehicle to infrastructure communications (V2I), there was no method for dynamically detecting any roadway sign utilizing AutonomouStuff's variant of Autoware. Speed limits signs, stop signs, and other traffic signs must be programmed in the HD maps and are associated with roadway segments.

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Transitions between speed limit zones are handled by the longitudinal controller and the response is dependent on the type of transition and the speed difference between the roadway segments. A subjective assessment of speed limit changes by the TRC Team found that the transition was sufficient. As a result of the ADS not dynamically detecting speed limits, it will be incumbent upon the safety driver to continuously confirm that the vehicle is traveling the legal speed. Speed limits changing as a result of construction or roadway rule change will require that the maps are updated to reflect the local speed limits. There is also a maximum speed limit in the parameter file which will not allow the vehicle to exceed a predefined speed regardless of roadway conditions. The default value for the top speed limit of the vehicle is 35mph. This value is recommended to be kept as testing was not done above this speed.

Stop signs, like speed limit signs, are solely a function of the HD maps. TRC Inc. did experience issues with stop signs at an intersection initially, which was a result of the stop signs being incorrectly programmed into the HD maps. This issue was quickly fixed during a map update, but this highlights that the HD maps must be correct or the operation of the ADS will result in inappropriate roadway behavior. The following were the original questions that TRC Inc. sought to answer during traffic sign testing.

Figure 6, below, analyzes a demonstrative test run to illustrate the performance of the vehicle at stop signs. In the figure below, the map indicates vehicle's path in a test run with two stop signs. Sign detection zone, which is defined as the region on map where the 'stopline_waypoint' variable has non negative values, is plotted on the map and cross referenced on the Speed plot.

As shown in the speed graph in Figure 6, the vehicle enters the stop sign detection zone, and does not immediately brake. When the braking does occur, the speed is reduced based on the current vehicle speed to bring the vehicle to a stop at a consistent distance from the stop line. This behavior was consistently shown at both stop signs in the SMARTCenter Urban Network, as desired.

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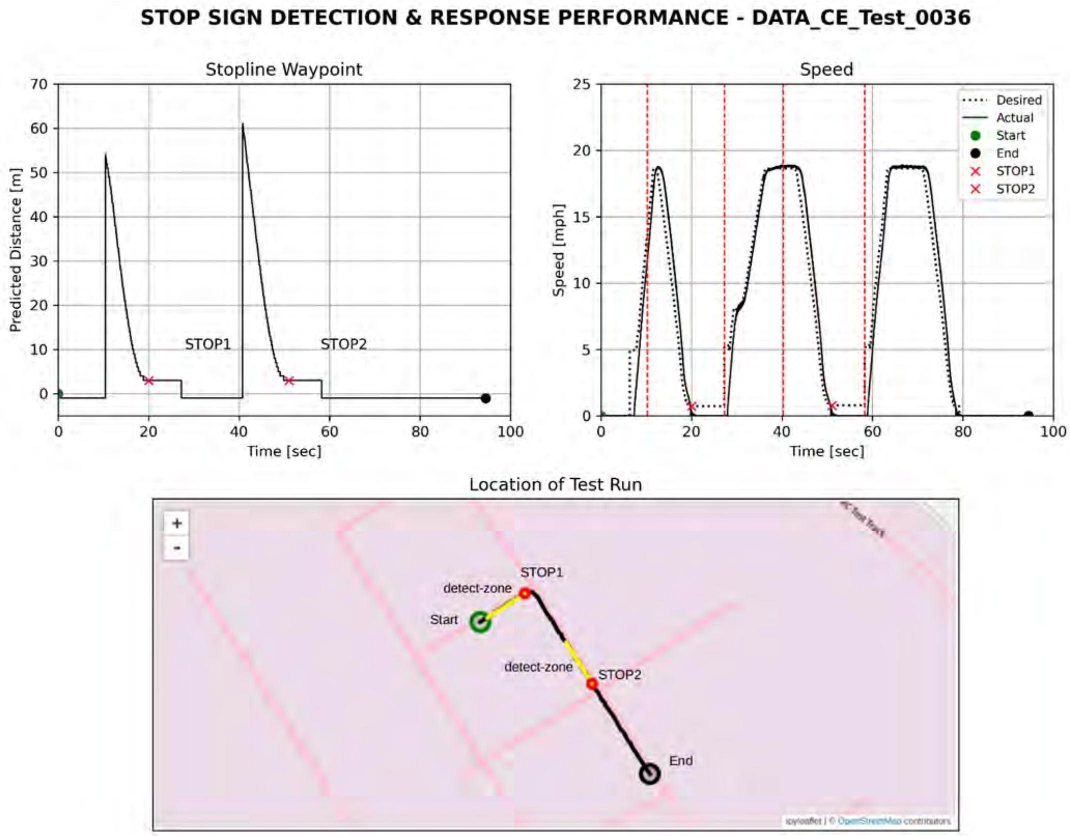

Figure 6. Stop sign detection anlaysis.

- Will the system detect and respond to speed limit changes?
  - Speed limits are solely determined by the HD maps. If there is a programmed speed change in the map, the vehicle will respond appropriately depending on the speed change.
- Are speed limits solely determined by the HD maps?
  - Yes, speed limits are solely a function of the HD maps.
- What speed limit signs can and cannot be detected?
  - There is no detection of speed limit signs.
- Will the system detect and respond to stop signs?
  - There is no detection of stop signs by the ADS. The ADS will only respond to a stop sign if it is programmed into the HD maps.
- Are stop signs solely determined by the HD maps?
  - Yes, stop signs are solely determined by the HD maps.

4.2.7 Detect and Respond to Traffic Signals

The TRC Team utilized a multi-lane intersection with a programmable traffic signal to test a variety of different potential scenarios involving traffic lights. The usable lanes, local traffic

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conditions, approach speeds, approach distances, desired lane operation, light timing, sun intensity, etc. were all different variables that were altered during extensive testing of traffic signals. A single intersection was tested due to reliance on the HD map. It should be noted that this reliance means that if a traffic light location were to change after being programmed in the HD maps, the ADS won't detect the traffic signal.

Traffic light detection is a three-step process and must be completed prior to a physical response of the vehicle. The following are the steps that must occur for the ADS to correctly identify a traffic signal and respond to it:

1. (Detection) The ADS employs computer vision to look in a certain Regions of Interest (ROIs) for traffic signals.
    a. These ROIs are programmed into the HD maps. The ADS is performing a geometric calculation based on the current location and information within the HD map to determine where within a picture a traffic signal should be located. This specific portion of the picture is passed to the next step.
2. (Detection) The ROI image is passed to a neural network that performs a color and intensity detection to determine what the state of the traffic signal is red, yellow, or green. This traffic state is passed to the rest of the ADS.
3. (Response) The ADS will treat the detected traffic signal state as either red or green with yellow being treated as red. The vehicle will proceed into the intersection or stop at the programmed in spot bar based on this signal.

Based on this process, there are multiple modes of failure that controlled environment testing repeatedly demonstrated. The ADS was discovered to have numerous issues determining the ROI. The first problem encountered was the result of the traffic signal being incorrectly programmed in the HD map and kept the signal from being detected. When the ADS does not detect a signal state, it will proceed through the intersection. The next issue was detected for multi-signal intersections where the system would switch between ROIs for different signals. The system only processes a single ROI at a time and the ADS must select one based on the lane. During many of the tests, the system would rapidly switch between two different ROIs at a multi-light intersection. In one test, the vehicle repeatedly would start and stop, responding interchangeably to a red and green ROI, until the ADS proceeded past the intersection's stop bar, at which point it would proceed through. If the vehicle were to approach an intersection where its lane has a red light and a neighboring lane has a green light, the vehicle could behave erratically and run the light. The third error discovered was an incorrect placement of the ROI bounding box in the image to where the traffic light was incompletely captured, meaning the light status could not correctly be determined. The software has a manual method to move the ROI images by a certain number of pixels, up/down/right/left, but the offset was not consistent.

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The ROI drift seemed somewhat random, and, during nearly all traffic signal testing, the TRC Team had to manually adjust the ROI location prior to intersection testing to perform the testing.

The second stage of detection also suffered from errors. The TRC Team was able to repeatedly demonstrate that the second stage of the detection could be fooled as a result of the sun. If the sun was in the correct position, the algorithm used to detect the color of the image would return a red-light state regardless of the actual traffic signal light state. Additionally, at the tested intersection, there are traffic signs that hang near the traffic lights. These signs could also reflect the sun in such a way to induce a false detection of a red-light. Due to the erroneous performance in the Controlled Environment settings, only two runs are analyzed further. Table 1 and Table 2 provide descriptions of four time stamps and corresponding to the four rows in the corresponding pictures, shown in Figure 7 and Figure 9. Each of these time stamps are followed by a graph plotting the detected light color and speed with a red 'x' marking the point for each time stamp, shown in Figure 8 and Figure 10.

Table 1. Analysis for run 1 - traffic signal detection.

Time	Criteria	Pass/ Fail	Comments
1	Detection	Fail	Light sequence for three lanes is [Yellow, Red, Red] it is read as [Red, Green, Green]. Traffic Light RoI is incorrect. Detected Light state applicable is incorrect.
2	Detection	Pass	Light sequence is [Red,Red,Red] it is read as [Red,Red,Red]. Traffic Light RoI is incorrect. Detected light state applicable is correct.
3	Detection	Pass	Light sequence is [Red,Red,Red] it is read as [Red,Red,Red]. Traffic Light RoI is incorrect. Detected light state applicable is correct.
4	Response	Pass	When the applicable traffic light turns green, vehicle proceeds through intersection. Traffic Light ROI is incorrect. However, applicable light state is correct

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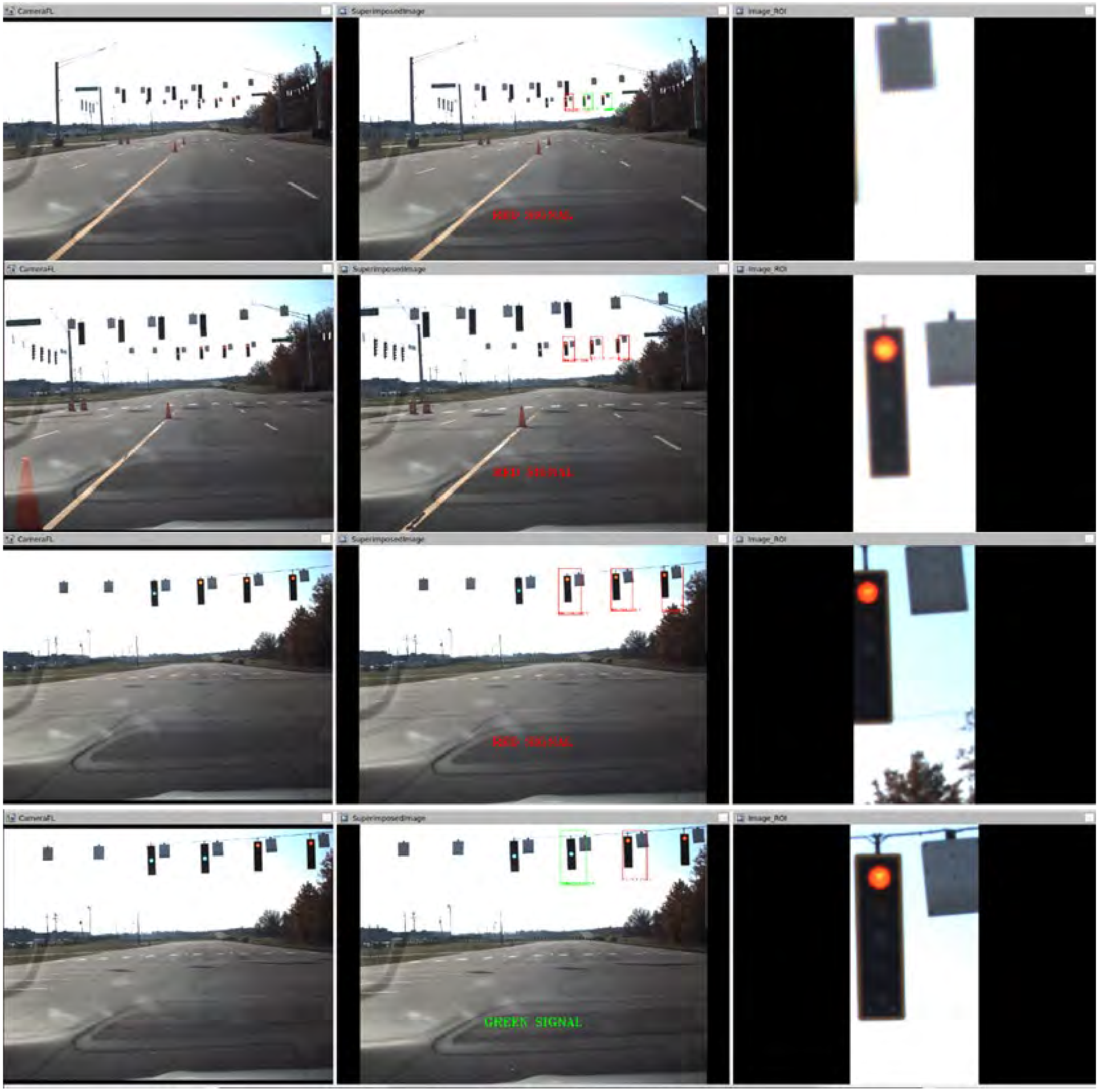

Figure 7. Set of four time steps corresponding to analysis for run 1- traffic signal detection.

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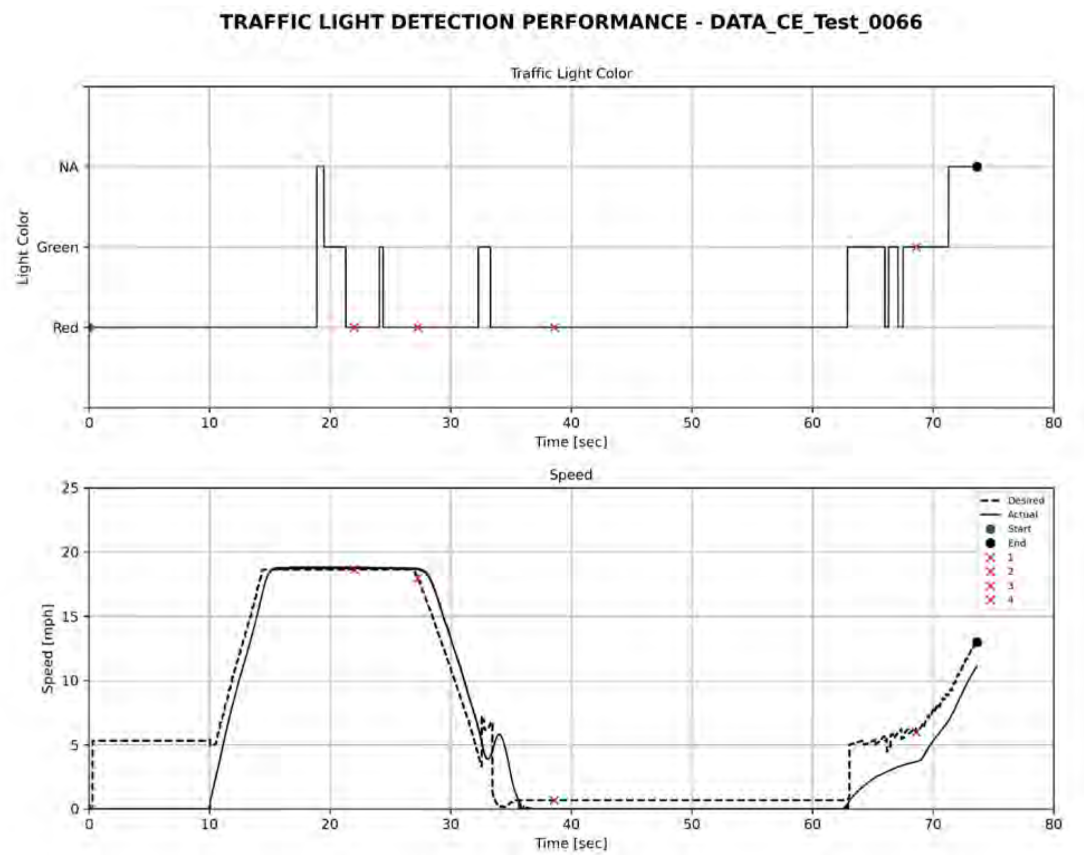

Figure 8. Traffic light detection for run 1.

Table 2. Analysis for run 2 - traffic signal detection.

Time	Criteria	Pass/ Fail	Comments
1	Detection	Pass	Light sequence for three lanes is [Green,Green,Green] it is read as [Green, Green, Green]. Traffic Light RoI is incorrect. Detected light state applicable is correct.
2	Detection	Pass	Light sequence is [Yellow,Green,Green] it is read as [Yellow,Green,Green]. Traffic Light RoI is incorrect. Detected light state applicable is incorrect.
3	Detection	Pass	Light sequence is [Red,Green,Green] it is read as [Red,Green,Green]. Traffic Light RoI is incorrect. Detected light state applicable is correct.
4	Response	Fail	The vehicle encroaches into intersection even when applicable traffic light color is Red.

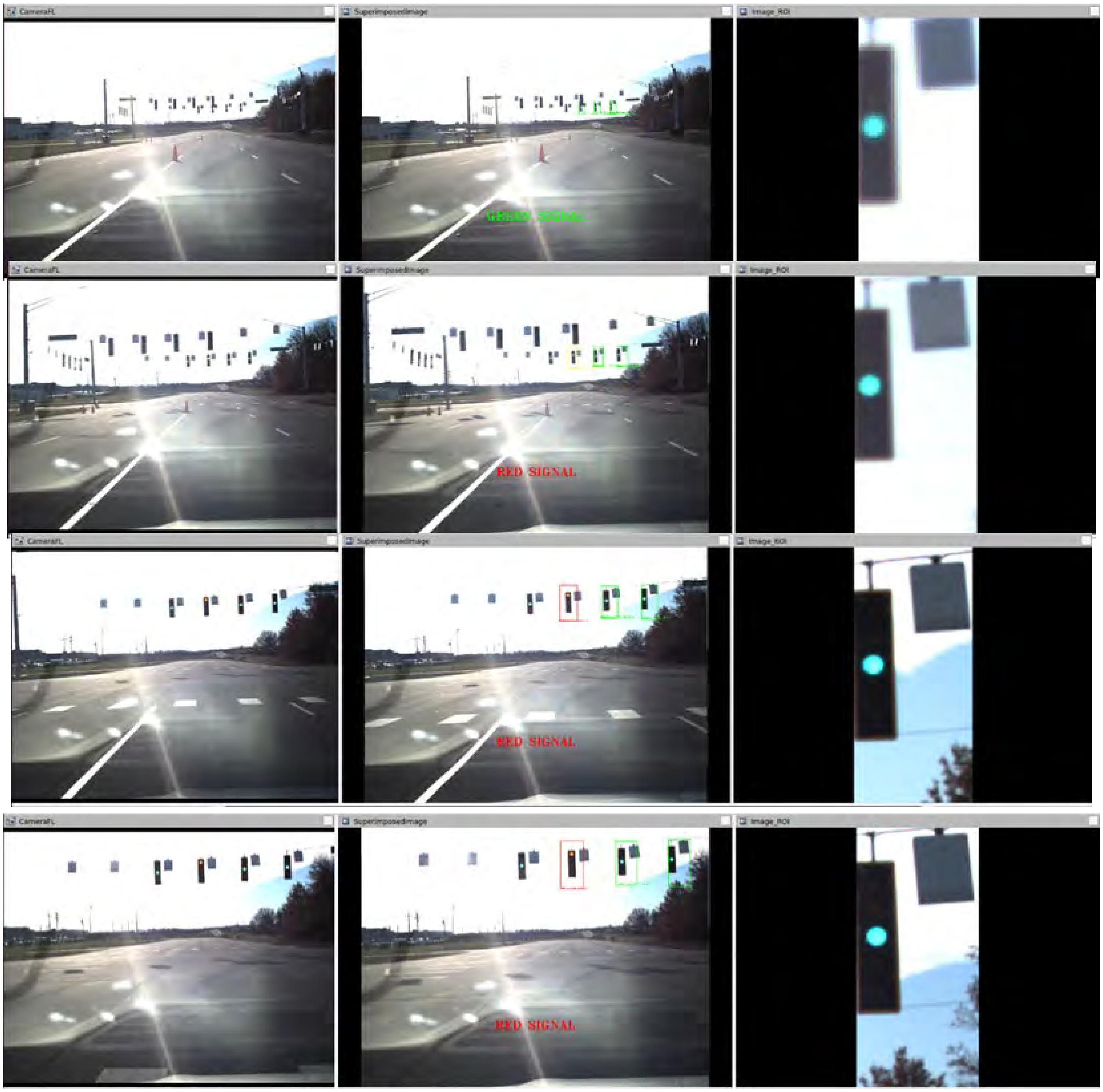

Figure 9. Set of four time steps corresponding to analysis for run 2- traffic signal detection.

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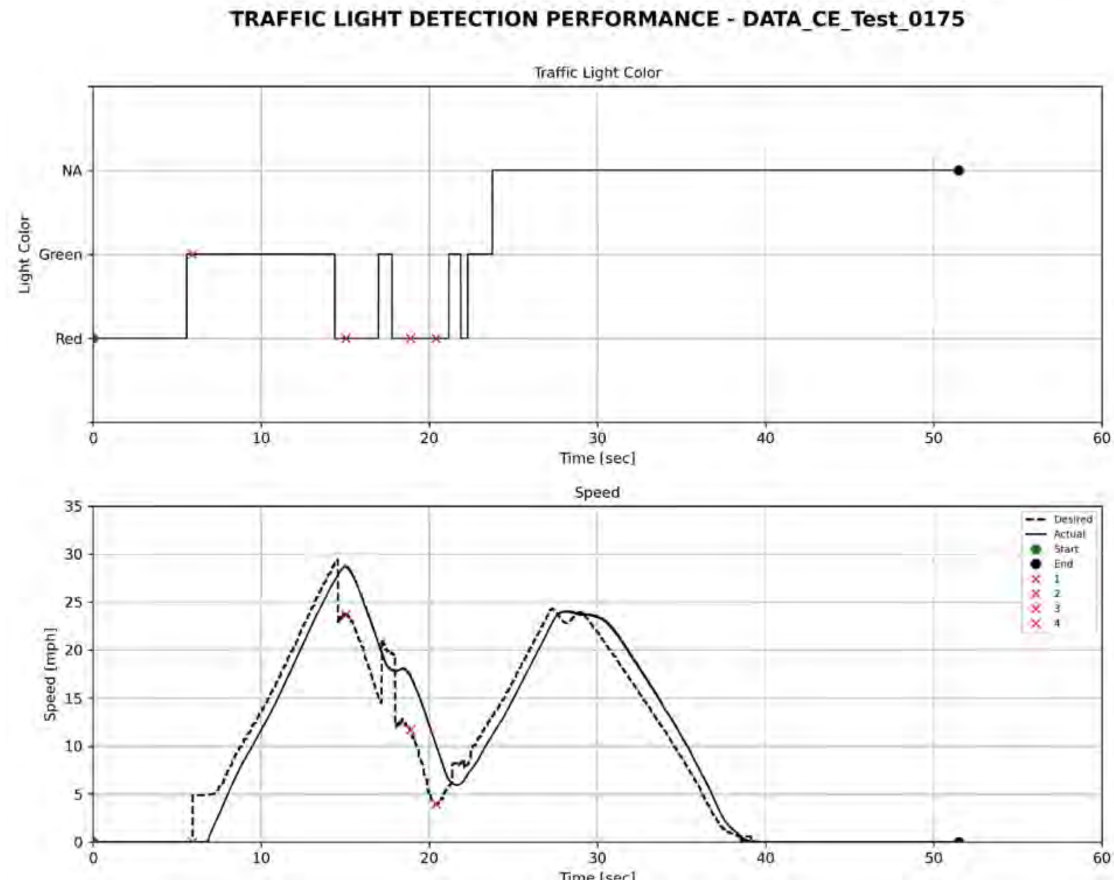

Figure 10. Traffic light detection for run 2.

The ADS, if the first two stages of detection were correct, correctly responded to traffic lights. Below are the original questions that the TRC sought to answer during traffic light testing.

- Will the system detect and respond to traffic light changes?
  - Yes, the vehicle will detect traffic light states and respond to the detected state. However, traffic lights are only detected if their location is programmed into the HD map. Furthermore, there are numerous issues associated with traffic signal response stemming from issues detecting the traffic signal or correctly determining the appropriate signal to response to when multiple signals are present.
- Are traffic lights solely determined by the HD maps?
  - Yes, traffic light locations are solely determined by the HD maps.

4.2.8 Detect and Respond to Objects

The TRC Team conducted extensive controlled environment testing to determine the limitations and the expected behavior to object detection. The testing started with basic roadway debris testing and extended into round two with testing of adjacent vehicles. The initial stages of testing

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revealed issues that would continue to be explored throughout testing. During the initial tests, the TRC put roadway debris of various sizes in the path of the ADS. The ADS was able to detect roadway objects until the LIDAR signature fell below twenty LIDAR points. The object detection software requires that the LIDAR point cloud signature meet or exceed a threshold (set to 20 in testing), based on the parameter file. As a result of the LIDAR sensor location and configuration, objects that are closer to the ground have fewer LIDAR points that could be returned. The location placement was a tradeoff so that the LIDAR can have 360°, but causes limits to objects that are low and close to the vehicle. This was demonstrated with a variety of objects that were clearly visible to the driver but did not register as an object because they did not return enough LIDAR points to be classified as an object. TRC Inc. was further able to demonstrate instances when objects were near the cutoff of this threshold and would oscillate between correctly detecting it. In this case, the vehicle would stop for the object, then start moving again repeatedly. This occurred until the object was so close to the vehicle that it fell below the cutoff range around the vehicle where LIDAR points are ignored. At which point, the ADS began to accelerate and the safety driver took control of the vehicle. Furthermore, it was discovered during the initial static testing that road objects that are not immediately in the path of the vehicle will not trigger an ADS response regardless of whether they are detected by the LIDAR or not. The TRC Team pushed this further by placing objects in an adjacent lane that partially obstructed the lane of travel of the ADS. The ADS was not able to successfully determine every instance where a lane intrusion happened resulting in the safety driver having to disengage the system. This included test cases where there was a strikable vehicle parked partially in the lane of travel of the ADS, and the ADS did not respond. Figure 11 shows an overview of the scenario. This helped inform how to conduct numerous tests in round 2 of controlled environment testing to find real word scenarios, where the ADS did run into the strikeable target while it was moving.

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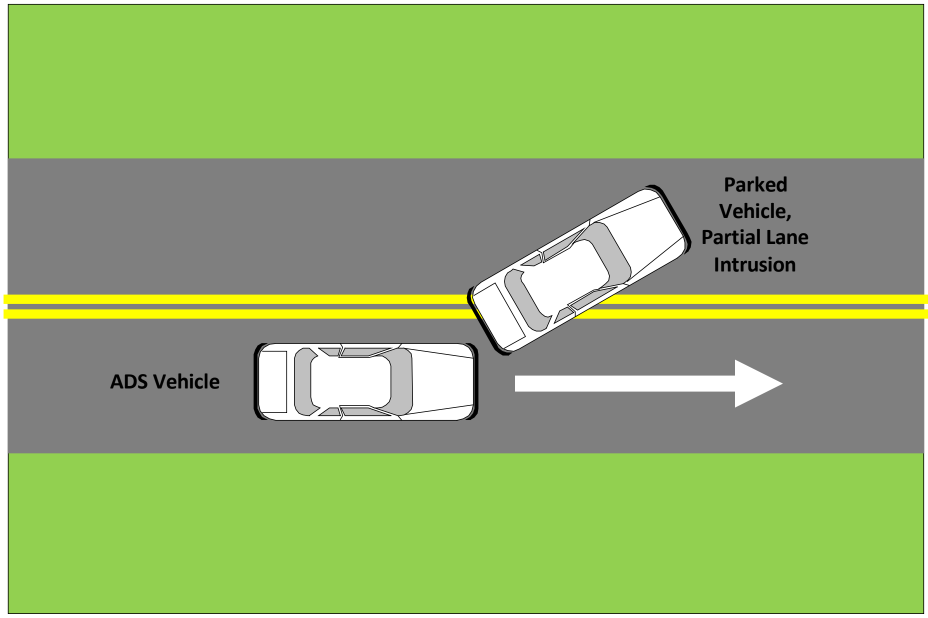

Figure 11: Partial Lane Intrusion

With static object detection and response complete, the TRC Team moved onto dynamic object detection and response. These tests involved operating the ADS in the presence of moving adjacent objects that, in some cases, were on a collision course with the ADS. However, all moving adjacent objects were stopped prior to any potential collision, as all destructive testing was reserved for Round 2. These initial dynamic object tests indicated that the ADS did not perform any sort of object trajectory tracking or extrapolation. Without any object trajectory tracking and extrapolation, there is potential for crashes to occur whenever the ADS or adjacent traffic need to change lanes. With the ADS only responding to objects within the immediate path of the vehicle and no trajectory extrapolation, the ADS did not respond correctly to imminent crashes that were about to occur. The following is a list of questions that the TRC Team initially sought to answer for this category of testing.

- What sensors are used in object detections?
    - The only sensor used in object detection/classification is the LIDAR sensor. The camera is used in traffic signal state identification.
- Are objects classified?
    - The ADS does attempt to classify objects based on their LIDAR signature. However, the classification system does not achieve a high rate of successful identification.
- Are object trajectories calculated?
    - No, object trajectories are not calculated. This has been shown in Round 2 of testing to be a source of hazard as the ADS will not respond to objects unless they are in the immediate planned path of the ADS.
- Are objects, classification, and trajectories recordable?

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    - Objects and object classifications are recordable.
- Is there a ground height clearance that objects won't be detected below?
    - This is dependent on a relationship between the height and width of the object. If the object is wide enough to trigger 20 points set as the threshold in the first row then it can still detect objects. The absolute minimum height an object can be detected is below the line of sight between hood of the vehicle and LIDAR.
- Is there a ground height clearance that objects won't be detected above?
    - Because the LIDAR is at the top of the vehicle, it can detect objects from at least a ground height that would be in the vehicles path.
- Is there a minimum size registry that objects must reach prior to vehicle response?
    - There is a minimum LIDAR point cloud that is required to be classified as an object. The default point cloud size is 20 points, and it can be edited in the parameter file.

5 Testing Round 2 – Complex and Targeted Use-Case Scenarios

5.1 Objectives

The focus of Round 2 of the Controlled Environment Testing was to subject the ADS-equipped vehicle to a focused set of full-system functionality tests, covering a mission critical array of operational features. Execution of Round 1 testing and evaluation informed the finalization of tests completed for Round 2 of testing. In this round, the tests were designed to answer questions such as:

- Can the vehicle navigate a multi-user roadway scenario safely?
- Understand the ADS stack's interactions with moving VRUs in intersections.
- Can the vehicle safely navigate dynamic traffic behavior in various roadway scenarios?
- Can it detect and respond appropriately to a variety of signalized and unsignalized intersections under different route-plans?

Through these tests, the TRC Team was able to develop an understanding of feature capabilities and evaluate nominal behavior of the stack. Developing an understanding of the behavior of the ADS stack helped inform the safety operator's expectations and how the vehicle will operate on public roadways. This information helped design safe on-road deployments for the ADS Demonstration Grant.

5.2 List of Tests

In the following sections, all the ADS test scenarios are further described in detail from the test execution point of view. The qualitative results are described, and the original research questions are addressed.

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5.2.1 Advanced Lane Keeping and Lane Changes

The first test addressed lane keeping/changing operations. The testing plan for this phase of testing was modified significantly when it was determined that the ADS will not change lanes and based on the method it utilizes for lane keeping, as described in Section 4.2.5. A detected object in the path of the vehicle will not prompt a lane change, the ADS stack will bring the vehicle to a stop and wait until the detected object is removed from the path of the vehicle before resuming operation. The only types of lane change that Autoware will perform is turning at intersections and lane splits in the HD map. It should be noted the latter is not treated as a lane change and used when new lanes are available for travel, and therefore does not check for adjacent traffic. Without effective lane changes, the majority of lane change testing was eliminated. Furthermore, the vehicle only utilizes GPS with RTK corrections combined with the HD maps for lane keeping, which eliminated vision based testing in this category. More information can be found in Section 4.2.2 and 4.2.5. Below are the research questions and their results.

- Does the vehicle detect lane lines?
  - No, the vehicle will not detect lane lines.
- Does the vehicle detect road edge?
  - No, the vehicle will not detect road edge.
- Does the vehicle incorporate these detections into motion control?
  - Not applicable.
- Should lane lines differ from HD maps, which factor is followed?
  - The vehicle has no active detection for lane lines; therefore, lanes as defined in the HD maps are followed. Localization is based solely on GPS+RTK correction. Error in those sensor readings can cause the vehicle to believe that it is following the lanes as defined in the HD maps when in reality its position differs.
- What are the limits that govern motion control when trying to maintain lane following?
  - There are a defined set of parameter values that govern motion controls. Furthermore, path planning breaks down paths into roadway segments that the motion control algorithm will follow. The exact limit on the radius of curvature the vehicle can take had some variation during testing, but there is an ultimate limit that will be reached. This is not deemed to be an issue for the anticipated turns in the deployment.
- How does lane following operation engage/disengage during dynamic events like turning?
  - Engagements and disengagements are governed the same in turns and are subject to the same issues determined in Round 1 of testing.

While the ADS vehicle is unable to make lane changes, traffic can change lanes ahead of the ADS vehicle. The TRC Team tested adjacent traffic moving into and out of the lane of operation of the

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ADS. Figure 12 shows a bird's-eye view of one such scenario, where a strikeable target vehicle cut in front of the ADS during operation. This test was performed in a variety of different permutations. The following is a list of the different variables that were altered during testing.

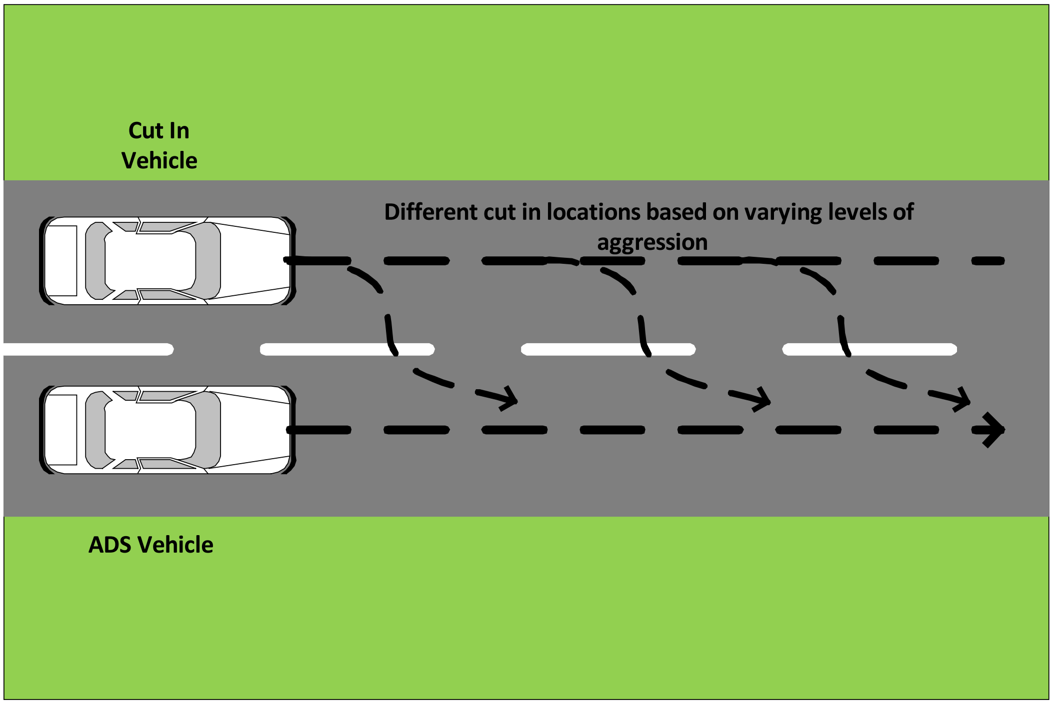

Figure 12: Lane Change Testing

- The adjacent traffic started ahead of the ADS vehicle in its lane of operation and moved to an adjacent lane. The same test was performed with the ADS vehicle being the lead vehicle.
- The adjacent traffic started ahead of the ADS vehicle adjacent to its lane of operation in and moved into the ADS vehicle lane of operation. The same test was performed with the ADS vehicle being the lead vehicle.
- Distances of cut in and cut out were varied starting at a large safe distance (2s+ margin) and progressively changing until cut in/out distances were unsafe.
- These tests were completed on straight and curved roadway segments.

This iteration of lane change testing confirmed that the ADS vehicle could safely navigate with adjacent vehicle cut ins/outs. When an adjacent vehicle cuts in front of the ADS vehicle, the ADS stack will slow down the vehicle to match the speed of the detected object in front of it. It should be noted that the same caveats apply that have been demonstrated in Round 1 of testing, that the vehicle must be detected and that Autoware will not respond to the detected object until it is directly in the path of the ADS.

5.2.2 Detect and Respond to Pedestrians

Testing was again heavily modified after the initial object detection was completed, as described in Section 4.2.8. As a result of Round 1 of testing, it was determined that only detected objects in the immediate path of the vehicle would result in altered vehicle behavior, as set in the parameter file. Please refer to Section 4.2.8 for further explanation of object detection. The first round of testing showed that smaller objects that were lower to the ground entering the vehicle path near the point of potential collision had the highest probability of resulting in a crash. The initial set of questions that this category of testing initially looked to answer are shown below.

- What sensors are used in object detection?
  - The only sensor used in object detection is the LIDAR.
- Are pedestrians classified?
  - There are limited capabilities of the software to perform object classification and should not be relied on for accurate classification.
- Are pedestrians' trajectories calculated?
  - No, pedestrians that are recognized do not have their trajectories calculated. This has been demonstrated to cause collisions with soft targets.
- Does the global planner dynamically update for pedestrians in lane?
  - No, if there is a pedestrian detected in the path of the vehicle the controls will adjust the vehicle speed to avoid a collision. This includes up to stopping in the middle of the lane.
- What remediation actions can be taken should pedestrians be detected in the vehicles path?
  - If there is a pedestrian in the pathway of the vehicle, it is incumbent upon the safety driver to take control of the vehicle. There are multiple modes of failure that have been demonstrated during destructive testing that can lead up to hitting a pedestrian. The pedestrian could not be recognized as an object.

The TRC Team utilized 4a adult and child strikeable targets to complete pedestrian testing. The targets were used with the targets static and dynamic testing and in straight line and curves. Below, in Figure 13, is a bird's-eye view of pedestrian testing where the 4a target was placed in different locations relative to the moving ADS vehicle. The static test results show that the vehicle would only respond to pedestrians in the immediate path as defined during the path planning stage of the ADS operation. This corresponds to the results seen during obstacle testing as described in Section 4.2.8. Furthermore, the vehicle was not consistent in detecting the child strikeable target because it did not generate enough LIDAR points.

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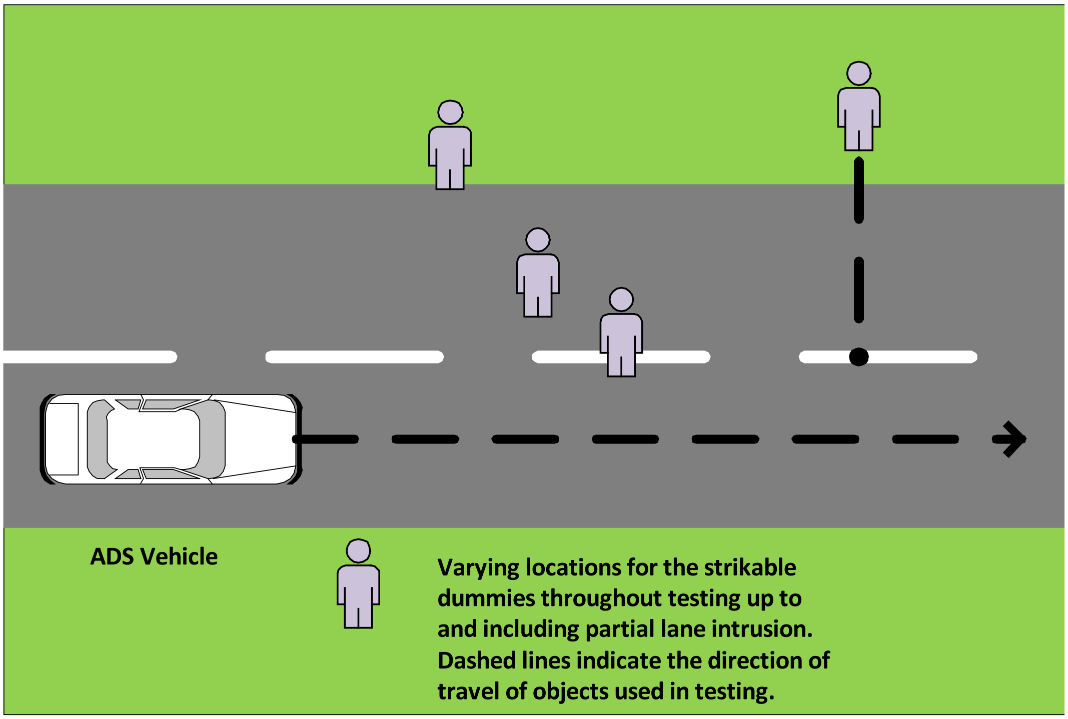

Figure 13: Static Pedestrian Testing

The dynamic tests resulted in hitting the strikeable pedestrians if they crossed in front of the vehicle path without sufficient time to stop when directly in front of the vehicle. Furthermore, the vehicle always detected the adult pedestrian, but still struck it during several tests. Similar to the static tests, the vehicle did not always detect the child pedestrian. This resulted in an increased number of times the child target was hit. The results were the same for both straight line and curved operation. The results from this test are consistent with other tests, which showed objects must be in the ADS vehicle's path before any action is taken.

5.2.3 Detect and Respond to Other Vehicles

Both in the initial round of testing as well as pedestrian testing, it became apparent that a vehicle that was not immediately within the path of the ADS but on a collision course with the ADS would pose potential collision threat. The TRC Team sought to test this exact scenario among a variety of other similar scenarios where the ADS vehicle would interact with nearby traffic. The team sought to answer the following questions.

- What sensors are used in object detections?
    - The sensor used in object detection is LIDAR.
- Are vehicles classified?
    - There are limited capabilities of the software to perform vehicle classification. Editing parameters can cause trees to be classified as bicycles or ignored

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completely. The object classification algorithm should not be relied on for accurate information.

- Are vehicle trajectories calculated?
  - No, vehicles that are recognized do not have their trajectories calculated. This has been demonstrated to cause accidents during destructive testing at TRC.
- Does the global planner dynamically update for vehicles in lane?
  - No, if there is a vehicle detected in the path of the vehicle the controls will adjust the vehicle speed to avoid a collision. This includes up to stopping in the middle of the lane.
- What remediation actions can be taken should an object be detected in the vehicles path?
  - If there is a vehicle in the pathway of the vehicle, it is incumbent upon the safety driver to take control of the vehicle. There are multiple modes of failure that have been demonstrated during destructive testing that can lead up to hitting a vehicle. The vehicle could not be recognized as an object. The vehicle's trajectory is not calculated and is not in the immediate path of the Autoware vehicle.

The TRC Team completed the following tests with adjacent vehicles to understand how the ADS responded to adjacent traffic.

- React to Stopped, Slower, and Decelerating Lead Vehicle
- React to Lead Vehicle Cut-in
- React to Decelerating Lead Vehicle Following Cut-out
- React to Lead Vehicle Cut-in and Brake
- Encounter Oncoming Vehicle in Adjacent Lane (Straight and Curved)

In these tests, the ADS vehicle was able to respond appropriately to adjacent traffic and slow or stop as expected. Again, the ADS vehicle will only respond to adjacent traffic once the traffic has entered into the immediate path of the ADS vehicle as defined in the path planning stage of ADS operation and if it has a sufficient LIDAR return. The latter requirement could potentially present challenges for motorcycles that will have a smaller LIDAR signature and might not meet the set threshold. Both present potential risks for the ADS operation on public roadways. Obscured vision operation was not completed and should be assumed to not be safe for operation, especially given the dependence on a single sensor.

In addition, intersection testing was completed, where the ADS vehicle and other traffic were on a collision course, but not in either's immediate path. Figure 14 shows an overview of the tests completed by the TRC Team. In both scenarios, the vehicle soft target was driven into the path of the ADS vehicle just before the point of collision. The testing was completed with clear line of sight the entire time between the two vehicles. Furthermore, the engineers monitored and confirmed there was appropriate LIDAR return. Given that the ADS software does not create trajectories, collisions occurred in both scenarios carried out as the strikeable target did not give the ADS vehicle sufficient time to stop once directly in the path. This is a very feasible scenario to occur on roads and demonstrates how the ADS would need to be monitored in a public setting. It will be incumbent upon the safety operator of the vehicle to be vigilant to these potential scenarios during any on road deployments.

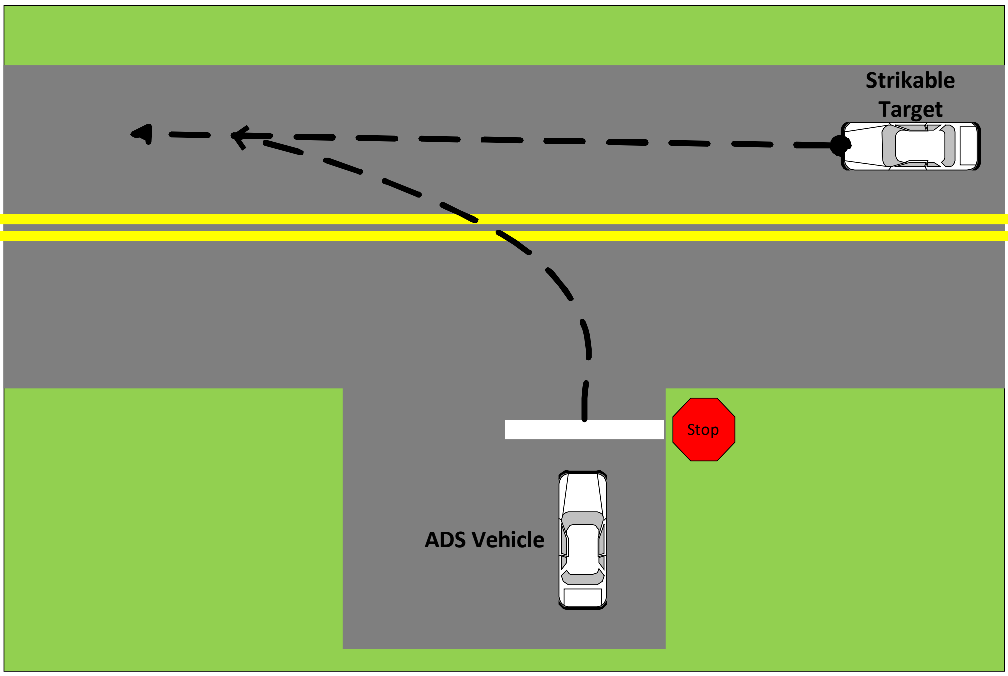

Figure 14: Destructive Soft Target Testing Overview

5.2.4 Intersection Approach and Departure

The originally planned testing for intersection approach and departure was curtailed due to the limitations seen during the first round of testing. The limitations were discussed in Section 4.2.7 and 4.2.8. As a result of these limitations, the planned intersection tests that could be executed were already completed in the pedestrians/VRUs and adjacent vehicle testing. The following list enumerates the responses that the originally posed questions for intersection approach and departure.

- Can the ADS software stack complete a protected right turn?
    - Yes, if there isn't conflicting traffic. The ADS cannot appropriately detect and respond to anything that may enter the vehicle's path and therefore is not able to safely execute this maneuver independently.
- Can the ADS software stack complete a protected left turn?

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- Yes via controls only. The ADS cannot appropriately detect and respond to anything that may enter the vehicle's path and therefore is not able to safely execute this maneuver independently.

- Can the ADS software stack complete an unprotected right turn?
  - Yes via controls only. The ADS cannot appropriately detect and respond to anything that may enter the vehicle's path and therefore is not able to safely execute this maneuver independently.
- Can the ADS software stack complete an unprotected left turn?
  - Yes via controls only. The ADS cannot appropriately detect and respond to anything that may enter the vehicle's path and therefore is not able to safely execute this maneuver independently.
- Will SPAT be incorporated into motion control?
  - No, SPaT is not incorporated in any turn.
- Will the vehicle proceed after coming to a stop?
  - Yes, the vehicle will proceed after coming to a stop.
- Will the vehicle proceed through a yellow?
  - No, while all three light states are detected, a yellow light is classified as a red light.
- What is the range of detection around the vehicle that is incorporated into motion control?
  - The maximum range of detection is around 60 m.
- How will the vehicle respond to visual occlusions?
  - Visual occlusions can affect either the LIDAR or the camera. If there is a visual occlusion of the camera, the vehicle will not respond to traffic light state. The default state is treated as green, so the vehicle will proceed through the intersection. If the LIDAR is a visually occluded, there will not be any response to objects in the path of the vehicle.
- Will the vehicle proceed past a stop bar to gain better detection range?
  - No such control/ state flow is used.

6 Test Requirements

Testing requirements to each test were defined in the Controlled Environment Test Plan published prior to Controlled Environment Testing. Generally speaking, tests were completed in fair weather conditions defined by:

- Temperatures ranging from 32°F and 80°F.
- Wind not exceeding 25 mph (11.2 m/s).

- High visibility during daylight operating hours.
- There was no testing during inclement weather.

Additionally, testing was completed under ideal roadway conditions with:

- Well defined lane markings.
- Lane widths between 3.35 to 4.57 m (11.0 to 15.0 ft).
- Well defined roadway edge.
- Strikeable targets that were easily visible.
- Manually driven roadway traffic that was easily visible.
- Generally, no roadway visibility obstructions.

Prior to testing, AutonomouStuff trained TRC in the calibration procedures required for the ADS. This included the intrinsic and extrinsic matrices required by the camera and LIDAR that the system employed. TRC Inc. employed the matrices calculated during the training period throughout the entirety of the controlled environment testing. As a part of the testing, TRC Inc. would occasionally vary some of the ADS calibration parameters to determine if altering these parameters would result in a different test outcome. However, the majority of testing was completed with the calibration parameters in their default state.

An overview of the instrumentation used for the tests described in this document is provided in Table 3.

Table 3. Test Equipment

Type	Output	Range	Accuracy
Tire Pressure Gauge	Vehicle Tire Pressure	0-150 psi	±0.5% of applied pressure
Platform Scales	Vehicle Total, Wheel, and Axle Load	0-20000 lb per each axle	±1.0% of applied load
GPS Speed Sensor[1]	SV and ME(s) speed	0.1-80 mph (0-35.8 m/s)	+/- 0.25% of full scale range
	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm

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Type	Output	Range	Accuracy
Multi-Axis Inertia Measurement Unit	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%
Data Acquisition System [Amplify, Anti-Alias, and Digitize]	Record Time; Velocity; Distance; Lateral, Longitudinal, and Vertical Accelerations; Roll, Yaw, and Pitch Rates; Steering Wheel Angle.	Sufficient to meet or exceed individual sensors	Sufficient to meet or exceed individual sensors
Data Flag	Signal from SV representing message to driver if presented	0 – 10V	Output response better than 10 ms
Vehicle Dimensional Measurements	Location of GPS antennas; Vehicles Polygon measurements.	N/A	0.04 in (1 mm)
Real-Time calculation of position and velocity relative to lane and Emb	Distance and Velocity to lane and Emb	Lat Lane Dist: ±30 m	±2 cm
		Lat Lane Vel: ±20 m/sec	±0.02 m/sec
		Long Range to Emb: ±200 m	±3 cm
		Long Range Rate: ±50 m/sec	±0.02 m/sec
Robotic Platform with Multi-Axis Inertia Measurement Unit	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm
	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%

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Type	Output	Range	Accuracy
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%

[1]Differentially corrected GPS should be used

7 Testing Conclusions

The following section breaks down the executed tests into their root causes analysis for issues discovered and extrapolates that behavior to potential on road issues.

7.1 High Level Overview

Autoware is an open-source automated driving software stack that is limited in its operational capabilities. Any operator that wishes to take this system onto roadways needs to have a clear understanding of the software limitations and ample first-hand experience with how to safely operate this software. The safety operator of the vehicle must be always engaged and ready to take control of the vehicle at a moment's notice.

Automated driving software stacks are a confluence of different software packages where each package is intended to accomplish a very specific goal that, when combined, can accomplish the tasks of driving. The requirement for such a complex system to accomplish the task of driving presents a high barrier to entry that stops potential researchers from testing their specific software package. As an example, a researcher might have come up with a novel means of identifying vehicle through computer vision. However, without the other parts of an ADS stack including other sensor perception, localization, path planning, and motion control, the researcher won't be able to test their computer vision algorithm in a complete ADS stack. Autoware was intended to fill this gap by giving researchers a baseline, open-source ADS stack that would allow them to plug in their own software into the stack for research purposes. Autoware was built and integrated by a large number of people across different organizations. The open-source nature of the stack that makes it beneficial for a researcher to test their computer vision algorithm, also carries limitations.

Autoware is a software stack built on early heuristics and rules-based controls. A heuristic and rules-based control strategy tends to be robust but inflexible to situations that fall outside of the control strategy. Fundamentally, this means that the controls strategy will work well for the limited number of scenarios it was intended to be used for, but the controls strategy will likely fail outside of that narrowly defined number of scenarios. This presents problems for public road testing as the ADS stack will eventually encounter scenarios outside of the build scope for the control strategy. This was proven during the adversarial testing completed as a part of the

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controlled environment testing. Even during tests that represented average driving conditions, Autoware was not able to perform to a sufficient level.

7.2 Software Bugs and Fault Diagnostics

During testing in numerous ADS categories there were unrelated software 'bugs' and other problems with insufficient fault diagnostics. The following are some examples of software bugs:

- There were numerous occasions during controlled environment testing where the ADS stack would disengage without warning to vehicle occupants. There was no underlying reason apparent in the software readout to explain why the ADS stack disengaged. This resulted in the vehicle drifting without the ADS stack controlling speed or steering angle.
- During each day of testing, there would be instances where the ADS stack would not engage when requested by the driver. There was no determined reason for the inability to engage. The first work around is to repeatedly have the operator attempt to engage the system. This typically resulted in the system engaging without changing any vehicle state. If that did not work, the next work around was to have the driver manually move the vehicle a few feet and attempt to re-engage again.

There were also numerous problems with system's fault diagnostics. Fault diagnostics is important in mobility systems because they are the first step in determining the source of an error or failed subsystem in a vehicle and is typically followed by a remediation action(s). These actions might be as simple as turning on a malfunction indicator lamp (MIL, also referred to as a check engine light) or could result in the torque production of the vehicle being limited. Fault diagnostics is more complicated for an ADS because of the nature of automating the driving and largely falls outside of the scope of this document. However, additional information on fault diagnostics in ADS can be found in ISO 21448. The following is one example of a failure that should have been caught by fault diagnostics:

- The ADS was able to be engaged without the LIDAR sensor being turned on, meaning the vehicle was effectively driving blind without any object detection.
    - This issue has been resolved with a simple fault diagnostic to address this issue. The vehicle can no longer engage without critical sensors being on and in communication with the vehicle.

Furthermore, without sensor redundancy in critical areas, there is no way to effectively detect faults that may occur. For example:

- There is only a single GPS sensor with RTK corrections in the vehicle and the default software configuration of the vehicle employs only that single GPS with RTK corrections as a means of localization. This means that if the GPS or RTK corrections are incorrect, the

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ADS will not be able to localize itself. Two different examples of this occurred during controlled environment testing:

- At the beginning of controlled environment testing, the RTK corrections in the system were inappropriately referenced to a datum. This resulted in the RTK signal effectively being inaccurate. As a result, the system could not localize itself and then was unable to detect traffic lights because the system did not know ‘where to look’ for the traffic control devices.
- During a different month of testing, for an unknown reason the location that the vehicle was receiving from the GPS signal was incorrect. This meant that the vehicle localized itself to be in the middle of a lane when in reality it was driving in-between two lanes.

- There is only a single means of computer vision in the vehicle, employing one Mako camera looking straight ahead. This single camera is only used in the detection of traffic light state (red, yellow, green). There is no other sensor on the vehicle employed in determining the traffic light state. The test team physically blocked this sensor resulting in the vehicle entering an intersection during a red light.

These examples for fault diagnostics demonstrate the limitation and immature nature of the software package.

7.3 Perception

The vehicle employs the LIDAR for the vehicle’s object perception. The only exception to this is the detection of a traffic light state, which is accomplished by a single Mako camera. Furthermore, the system does not perform trajectory tracking/extrapolating. This means that even if a vehicle, VRU, or object is detected, the ADS will not respond unless it is in the immediate path. TRC Inc. was able to demonstrate this with numerous soft target collisions, in which the ADS vehicle pulled into oncoming traffic or failed to stop when someone pulled in front of them. The ultimate result of this is that the safety operator needs to be aware of this limitation by looking out for potential collisions to avoid these situations. A summary of the perception issues is listed below.

- Unable to detect roadway objects or debris if it is below a certain LIDAR signature. Given the physical location of the single LIDAR sensor, this means that low-lying roadway debris or objects will almost certainly not be perceived.
- Children in front of the vehicle were not detected in the path of the vehicle.
- The system does not complete trajectory tracking/extrapolating. This means that even if a roadway user is detected, the system may not respond to it appropriately if it is not in the immediate path of the vehicle. This resulted in numerous soft target collisions at TRC.

7.4 Localization

Currently, the system is entirely dependent on GPS/RTK corrections for localization. Reliance on a single sensor for any safety critical operation presents its own safety risks. Beyond reliance on a single sensor, the localization system did experience isolated problems with localization. The TRC Team was unable to determine the root cause of these isolated problems. The isolated problems resulted in the ADS localizing itself to an inappropriate location. For example, in one instance the ADS localized itself to being in the middle of a lane when in reality it was driving in between two lanes. Other similar problems were detected but resolved.

7.5 Motion Control and Path Planning

Overall, there were several issues observed in both the lateral and longitudinal control of the vehicle. It was determined that the problems observed were the result of the following issues in the path planning systems.

- Lateral control had issues following a curve in a smooth fashion; rather, it broke the curve into straight line segments. Depending on the radius of the curve, this could result in jerky operation.
- Lateral control in intersections results in driving behavior that would be considered abnormal to a normal driver.

In addition, longitudinal control would not stop at the end of the path as designated by the technical operator. Instead, the vehicle would begin to decelerate at the end point. This means that if the end point is placed right before an intersection, the vehicle will proceed into the intersection. No issues were directly detected as a result of the motion control.

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8 Appendix A – Testing Equipment and Facility

A.1 Testing Equipment

OXTS RT3000 V2 and V3:
- IMU and GPS unit
- Measures position, orientation and dynamics of a vehicle in real-time
- Position accuracy: 2 cm
- Slip angle accuracy: 0.15°
- 100 Hz data output rate

OXTS RT-Range:
- V2V, V2X and Vehicle-to-lane measurements in real-time
- Up to 1km range between hunter and targets
- Can measure up to 4 moving targets simultaneously

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Freewave Differential Correction:

- Use local base station's signal to improve GPS' accuracy

Brake and Throttle Robot:

- 2 SEA units and 2 ABD units
- Ability to maintain a constant speed or acceleration within tolerance
- Can perform correct amount of deceleration

Steering Robot:

- 1 SEA unit and 1 ABD unit
- Path following ability
- Lane centering driving ability

ABD Guided Soft Target (GST):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 100 km/h (27.8 m/s)
- Forward acceleration up to 0.2g and deceleration up to 0.8g
- Synchronization with the test vehicle with path following ability
- Has heavy duty ramps for Semi testing

DSD Ultraflat Overrulable Robot (UFO):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 65 mph (29.1 m/s)
- Forward acceleration up to 0.3g and deceleration up to 0.6g
- Synchronization with the test vehicle with path following ability
- Removable side ramps and batteries

DSD Pedestrian Arm:

- DSD UFO's extension kit to pull pedestrians
- Attaches to the UFO and detaches on impact to the pedestrian

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A.2 Testing Targets

NHTSA Strikeable Surrogate Vehicle (SSV):

- Allows for testing of constant speed, accelerating and decelerating lead vehicle
- Representative of small hatchback from rear only

EuroNCAP Soft Car 360:

- Representative of a small hatchback from all angles
- Can take impacts and be reassembled in 10-15 minutes

Pedestrians: Static Adult and Static Child

- 4activeSystmes static dummies that replicate properties of stationary pedestrians in size, shape and radar cross section
- Can take impacts up to 60 km/h (16.7 m/s)

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Pedestrian: Bicyclist

- 4activeSystmes dummy that replicate properties of a bicyclist in size, shape and radar cross section
- Can take impacts up to 60 km/h (16.7 m/s)

Pedestrian: Motorist

- 4activeSystmes dummy that replicate properties of a motorist in size, shape and radar cross section
- Can take impacts

Sign Inventory

- Speed signs
- Traffic signs

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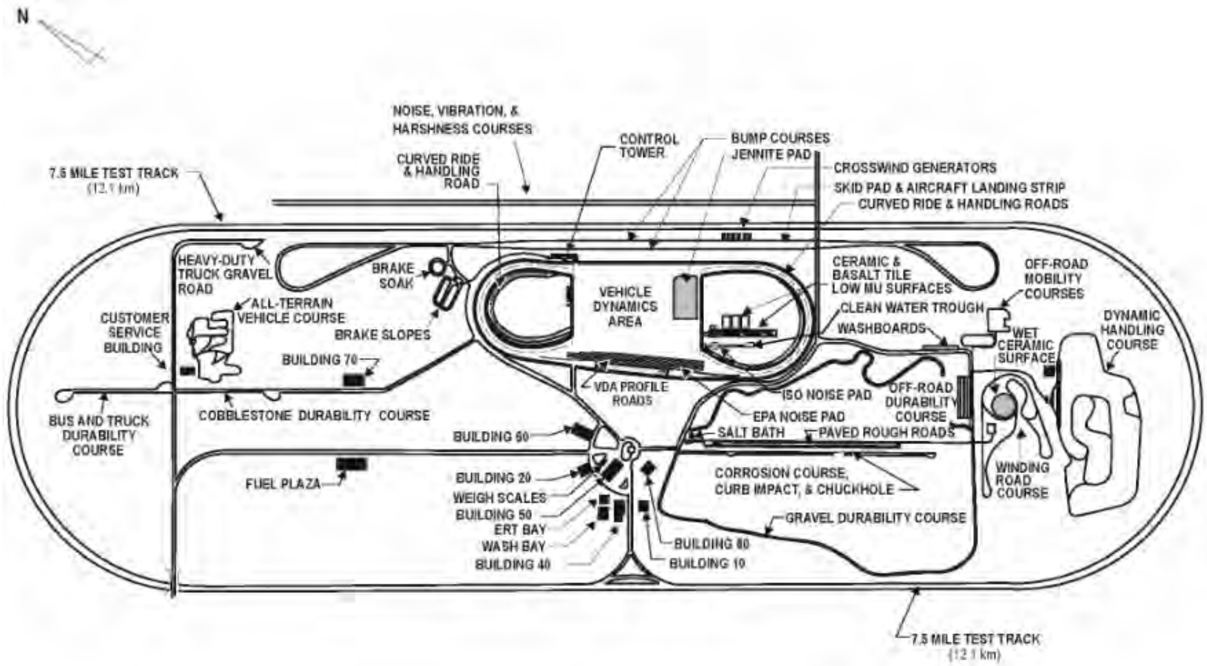
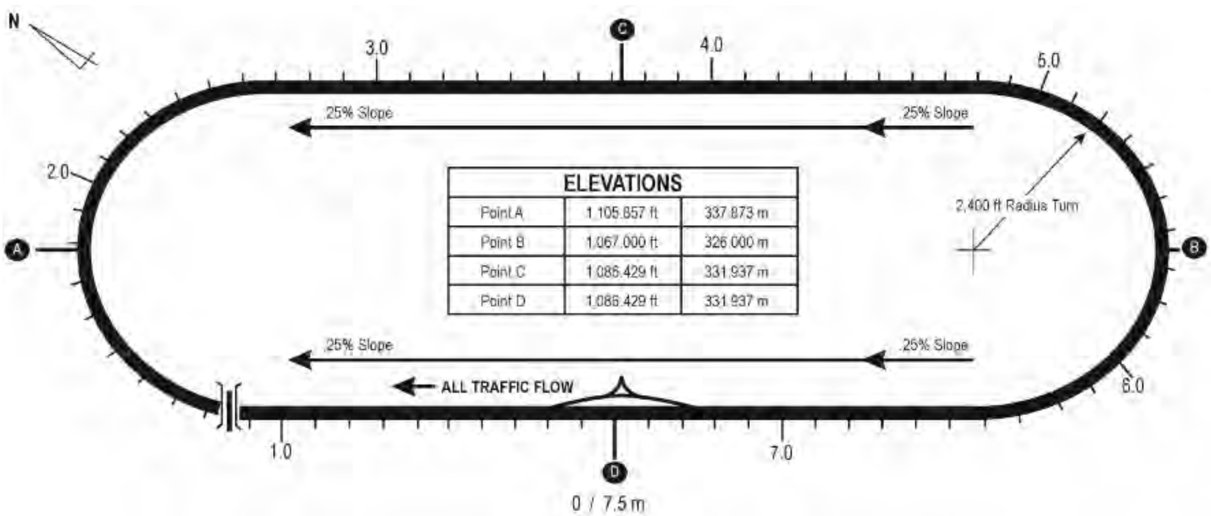
A.3 Testing Facilities



TRC Overall facility



ELEVATIONS		
Point A	1,105.857 ft	337.873 m
Point B	1,067.000 ft	326.000 m
Point C	1,086.429 ft	331.937 m
Point D	1,086.429 ft	331.937 m

7.5 miles High-speed Test Track

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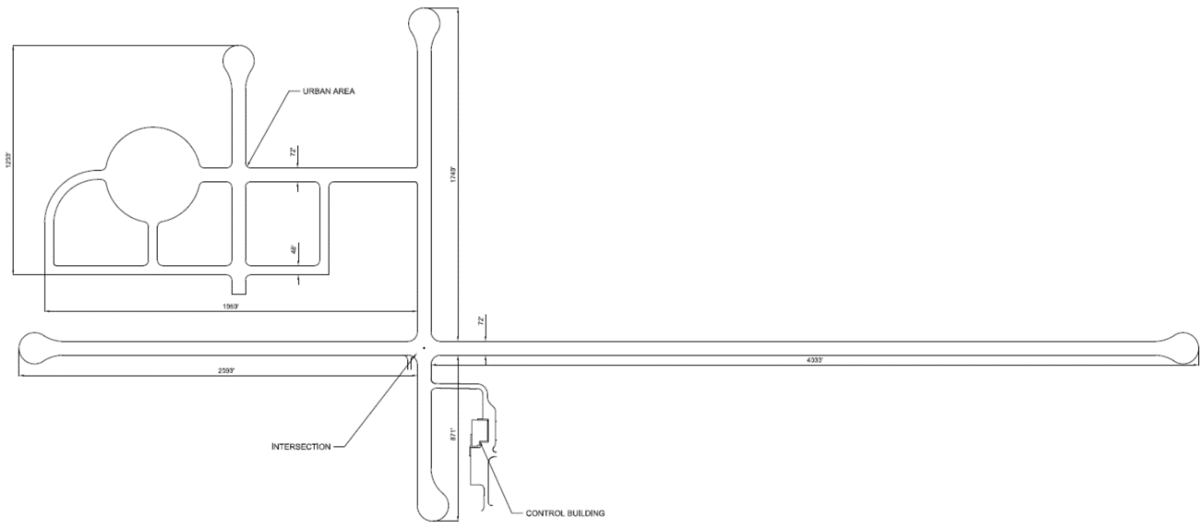
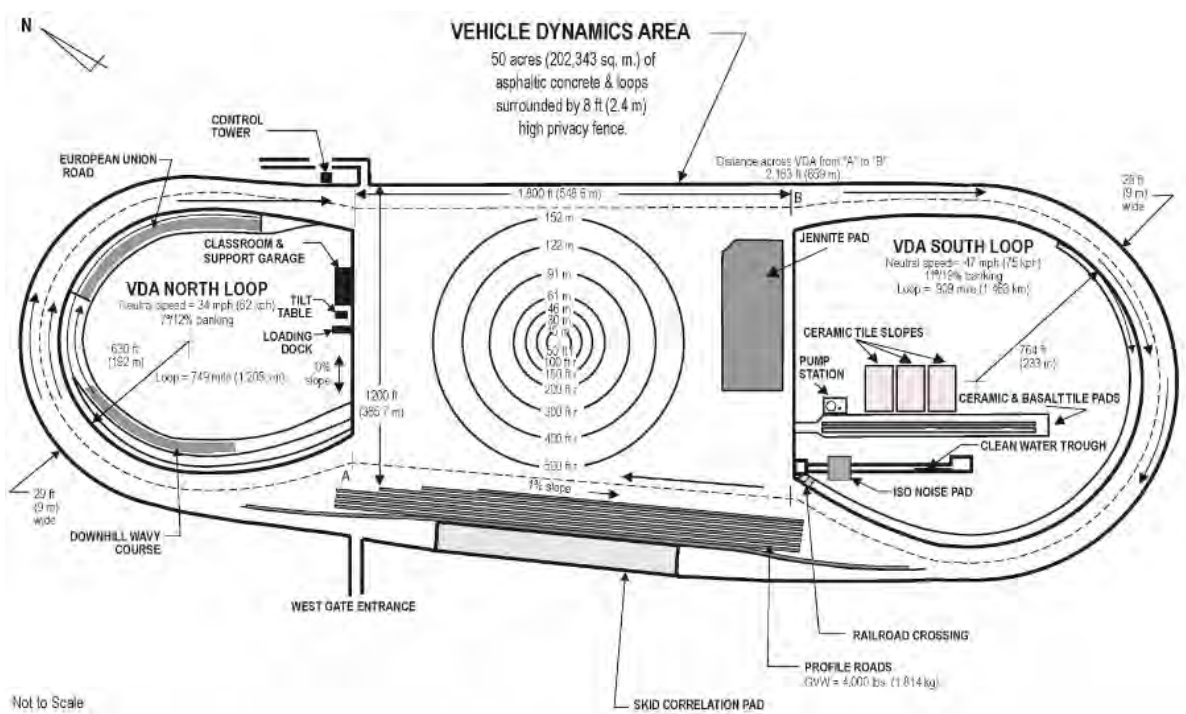


SMARTCenter

6-lane high-speed intersection with larger leg of 1.2 miles for heavy duty vehicles to reach up to 65 mph (29.1 m/s) at the intersection. Urban network with city blocks and 152 m (500 ft) radius roundabout.



Vehicle Dynamics Area

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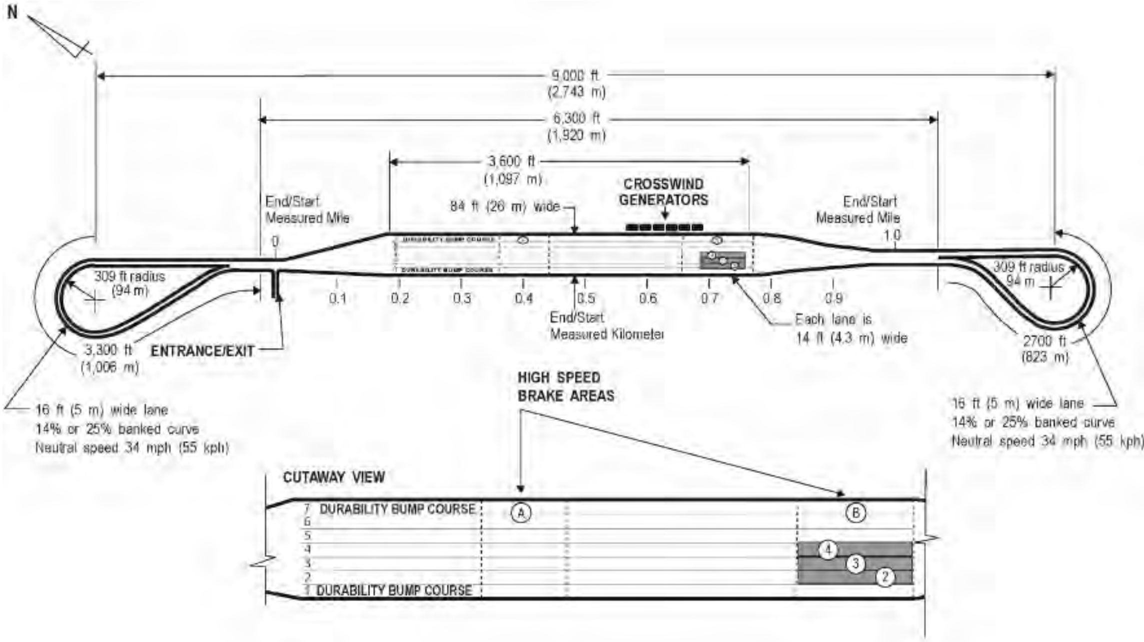

Skid Pad

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Appendix B4
TRC Deployment Plan

Deployment Plan – DATA in Ohio Phase 1

Objective:

The objective of Phase 1 deployment is to gather data needed to develop an understanding of the challenges in developing and operating an ADS in rural environments. The data in Phase 1 will be collected using the open source Autoware ADS stack.

Vehicle and Stack background:

The Phase 1 deployment uses Autoware version OAP8 ENU projection provided by AutonomousStuff. This ADS stack is a collection of packages developed in Robot Operating System 1(ROS1). Due to the limited ODD of Autoware there will be three modes of data collection to maximize the amount of data collected.

Modes of Data Collection

Bucket 1 (Raw Sensor Mode)

In Bucket 1 the raw sensor data from lidar, and camera sensors will be recorded which can be later used by researchers for running various object detection and motion prediction algorithms, as well as by regulators for the purpose of developing virtual/physical tests and operational specifications for candidate systems. The features of this bucket Include:

- Lack of dependence on the Autoware global path planning and control algorithms.
- Safety driver will be in complete control of the vehicle at all time.
- Complex routes can be created as the path planning of Autoware will not be active.
- Complex interactions with the traffic environment can be replicated.

Bucket 2 (Shadow Mode)

In Bucket 2 the path planning and the control algorithms from ADS will be active in background (shadow) but the safety driver will be in complete control. The objective of this mode is to evaluate the ADS performance while the safety driver is manually controlling the vehicle. This mode enables the user to gather datasets without disengaging the control algorithm. The features of this bucket include:

- Dependence on the Autoware global path planning algorithm.
- Safety driver will be in complete control of the vehicle but has to strictly follow the path generated by Autoware.
- Any deviation from the planned path will result in data loss (mode deactivates once driver has to deviate from the path)
    - Raw sensor data (Bucket 1) will still be recorded in such cases but outputs specifically related to having the automation stack active will be lost.
- No lane changes are allowed in this bucket.

Bucket 3 (ADS Stack Active Mode)

In Bucket 3 the path planning and the control algorithms from ADS will be active and will control the motion of the vehicle. A safety driver will be monitoring the vehicle motion and should be prepared to takeover (disengage) control from the ADS in all safety critical scenarios. The objective of this mode is to evaluate the performance of the ADS stack and generate the evaluation metrics from the recorded dataset. The features of this bucket are:

- Dependence on the Autoware global path planning, perception and control algorithm.
- Safety driver has to monitor the system and take control/disengage system in case of unsafe maneuvers by the ADS stack.
- Any disengagement by the driver will end the data recording and lead to data loss.
  - Raw sensor data (Bucket 1) will still be recorded in such cases but outputs specifically related to having the automation stack active will be lost.
- No lane changes are allowed in this bucket.
- Speed limit of 35mph.

ODD

ADS Active (Bucket 3):

- No lane changes required in the routes.
- Clear weather with no sun glare directly in the camera
  - Sun glare affected the traffic lights detection in the CE testing.
  - Testing will be suspended when sun angle relative to the horizon is less than 15 degrees.
- Low traffic density.(10 a.m to 1 p.m)
- Unprotected left and right turn are not allowed as the ADS will not yield to traffic. Safety driver has to disengage and try to engage after executing the turn.
- Protected left and right turns allowed if the traffic light detection module works.

Shadow Mode (Bucket 2):

- No lane change in the routes.
- Strictly follow the Autoware planned route.

Raw Sensor Mode (Bucket 1):

- No specific restrictions compared to Bucket 1 and Bucket 2

Data Collection Efficiency Measurements

The data collection efficiency for each mode will be calculated by the formula below

$$\eta_{bucket} = \frac{L_{bucket\ active}}{L_{route}}$$

Where n_{bucket} = bucket data collection efficiency, $L_{bucket\ active}$ = the section of the route where the bucket was active, L_{route} = the total length of the route.

For Bucket 3, an additional efficiency metric would be number of disengagements by the driver in a route for safety reasons. Additional parameters like the number of disengagements per mile can be generated from the recorded disengagements.

Data Collection Mode	**Estimated Bucket Efficiency**
Bucket 1	
Bucket 2	
Bucket 3	

Bucket Number	Range of Data Collection (Time spent or Number of Loops) %
I	30% - 60%
II	30% - 40%
III	10% - 30%

The above table shows the range for each bucket. If the efficiency of data collection from a corresponding bucket is high. The upper limit (% of data collection) will be used for deployment. Bucket 1 will be reduced if Bucket 2 and Bucket 3 have a higher collection efficiency.

Efficiency % from part 1 of deployment	Data collection %
More Than 80%	Higher Limit (30% (III); 40% (II))
Between 50% and 80%	15% (III); 35% (II)
Less Than 50%	10% (III); 30% (II)

The other parameter for the data collection efficiency is defined as the combined efficiency of the software, hardware system and the collection efficiency of the team.

$$\eta_{collection} = Hours\ of\ data\ collected$$

Summary of Deployment 1 Collection Plan

Collection Day	Bucket 1	Bucket 2	Bucket 3	Route(s)	Estimated # of Runs	Notes
1	X	X		Bellefontaine	20	
2	X	X	**O**	Bellefontaine	10	
3	X	X		Bellefontaine	15	
4	X	X	**O**	Bellefontaine	15	

Collection Day	Bucket 1	Bucket 2	Bucket 3	Route(s)	Estimated # of Runs	Notes
5	X	X		Marysville	20	
6	X	X	**O**	Marysville	15	
7	X	X		Marysville	20	
8	X	X	**O**	Marysville	18	
9	X	X		Avery	10	
10	X	X	**O**	Avery	15	
11	X	X		Avery	20	
12	X	X	**O**	Avery	15	
13	X	X		Renner	15	
14	X	X	**O**	Renner	15	
15	X	X		Renner	15	
16	X	X	**O**	Renner	15	
17	X	X		High Street	15	
18	X	X	**O**	High Street	15	
19	X	X		High Street	20	
20	X	X	**O**	High Street	15	

"**O**" - Bucket 3 data collection for a particular route will be based on ADS system performance, e.g if the Bucket 3 data collection for Bellefontaine will have few driver disengagements and system performance is satisfactory then the bucket 3 collection will be tested in other subsequent routes.

Data Collection Mode	Estimated # of Runs*	Estimated Miles*	Collection Vehicle
Bucket 1	202	796	TRC Fusion
Bucket 2	101	398	TRC Fusion
Bucket 3	15	60	TRC Fusion
Total	**318**	**1254**	

Deployment Timeline:

S No.	Task/Milestone	Schedule
1	Driver Training	31st March - 7th April
2	Bellefontaine	11th April – 18th April
3	Marysville	20th April – 27th April
4	Avery	29th April – 6th May
5	High Street	9th May – 16th May

*Estimated number of runs will vary based on system performance. If the ADS (Autoware) on road performance is good (few operational and functional issues), then the higher bucket (2/3) proportion will be increased.

Appendix A – Route Specifications for Phase 1 Deployment

Bellefontaine

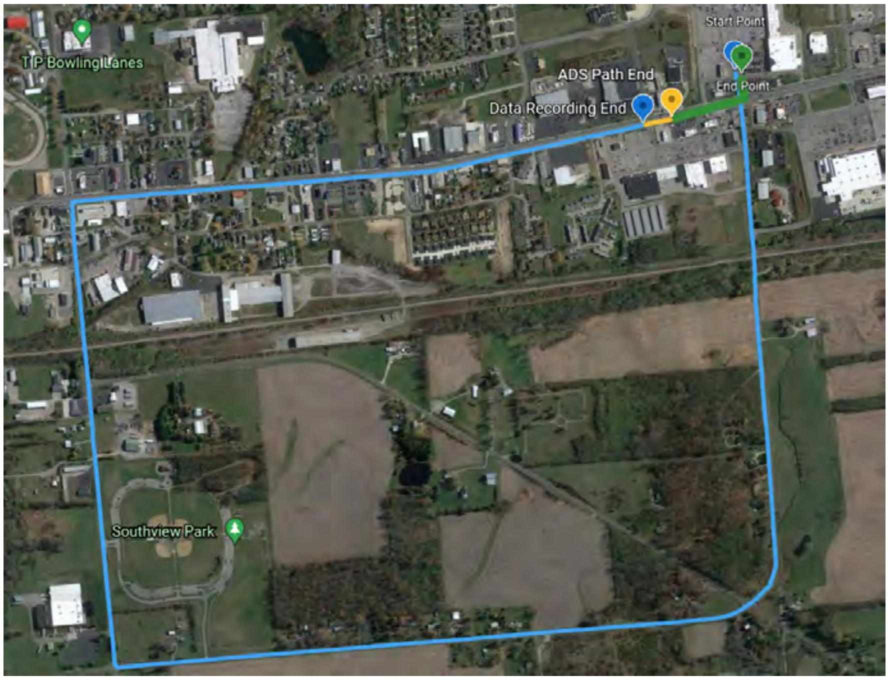

Figure 1: Bellefontaine Route: Travel Direction - Clockwise

Route Description:

Route Length	5350m (3.3 miles)
Estimated Travel Time	10 to 15 minutes

Potential issues/restrictions

- Speed limit over 35mph (50 mph)
- Unprotected rail crossing.

The data collection process will be divided into two parts.

Part 1(Learning Phase)			
Collection Day	**Bucket**	**Estimated # of Runs**	**Notes**
1	I & II	20 runs	Adaptation phase for the driver for route & following the planned route by autoware
2	II & III	15 runs	Data collection to understand critical locations for ADS
Part 2(Adaptation of Data collection distribution from efficiency for each bucket)			
3	I & II	15 runs	
4	II & III	20 runs	

Marysville

Figure 2. Marysville Route

Route Description:

Route Length	4023 m (2.5 miles)
Estimated Travel Time	10 to 15 minutes

Part 1(Learning Phase)			
Collection Day	**Bucket**	**Estimated # of Runs**	**Notes**
1	I & II	20 runs	Adaptation phase for the driver for route & following the planned route by Autoware
2	II & III	15 runs	Data collection to understand critical locations for ADS
Part 2(Adaptation of Data collection distribution from efficiency for each bucket)			
3	II & III	15 runs	
4	I & II	20 runs	

Renner

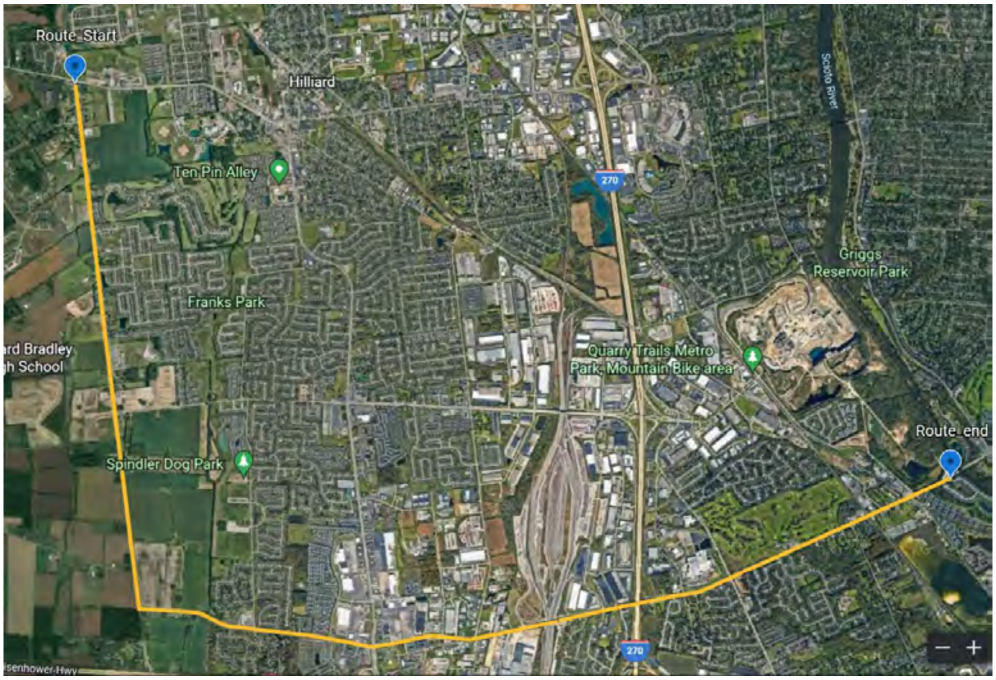

Figure 3. Renner Route

Google maps: link

Route Description: -

Route Length	14162 m (8.8 miles)
Estimated Travel Time	20 to 25 minutes

Part 1(Learning Phase)			
Collection Day	**Bucket**	**Estimated # of Runs**	**Notes**
1	I & II	15 runs	Adaptation phase for the driver for route & following the planned route by autoware
2	II & III	10 runs	Data collection to understand critical locations for ADS
Part 2(Adaptation of Data collection distribution from efficiency for each bucket)			
3	II & III	10 runs	
4	I & II	15 runs	

North High

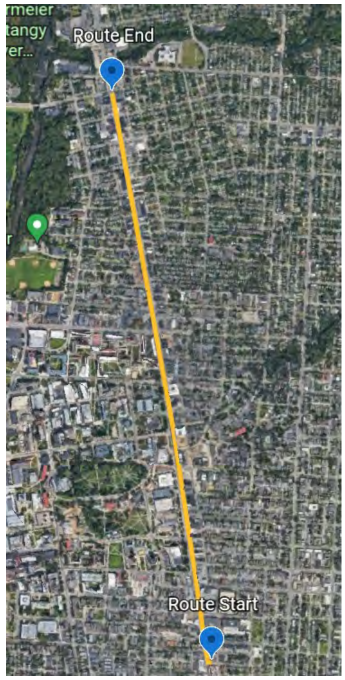

Figure 4. North High Route

Google maps: link

Route Description: -

Route Length	2896 m (1.8 miles)
Estimated Travel Time	10 to 15 minutes

Part 1(Learning Phase)			
Collection Day	**Bucket**	**Estimated # of Runs**	**Notes**
1	I & II	15 runs	Adaptation phase for the driver for route & following the planned route by autoware
2	II & III	10 runs	Data collection to understand critical locations for ADS
Part 2(Adaptation of Data collection distribution from efficiency for each bucket)			
3	II & III	10 runs	
4	I & II	15 runs	

Avery Run

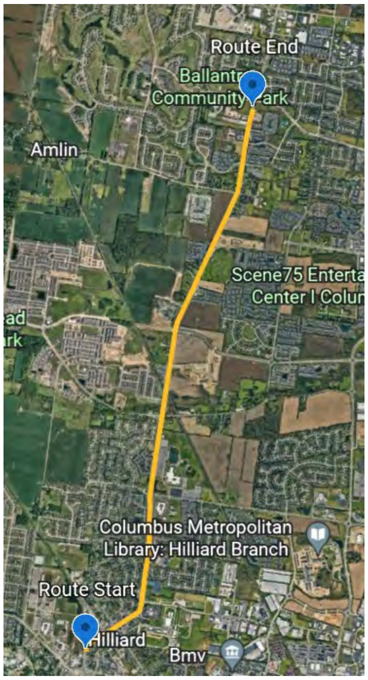

Figure 5. Avery Run Route

Google maps: [link]

Route Description: -

Route Length	6115 m (3.8 miles)
Estimated Travel Time	8 to 10 minutes

Part 1(Learning Phase)			
Collection Day	**Bucket**	**Estimated # of Runs**	**Notes**
1	I & II	15 runs	Adaptation phase for the driver for route & following the planned route by autoware
2	II & III	10 runs	Data collection to understand critical locations for ADS
Part 2(Adaptation of Data collection distribution from efficiency for each bucket)			
3	II & III	10 runs	
4	I & II	15 runs	

Appendix B5
TRC Passenger Vehicle Controlled Environment Summary for Apollo

Passenger Vehicle Controlled Environment Summary for Apollo

Prepared By:

Transportation Research Center, Inc.

Prepared For:

DriveOhio
The Future of Smart Mobility

07/31/2023

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List of Acronyms, Abbreviations and Symbols

ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
GPS	Global Positioning System
NHTSA	National Highway Traffic Safety Administration
ODD	Operational Design Domain
SV	Subject Vehicle
SAE	Society of Automotive Engineers
SSV	Strikeable Surrogate Vehicle

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1 Introduction

The Transportation Research Center Inc. (TRC Inc.) has completed the Controlled Environment (CE) Testing for the Automated Driving Systems (ADS) Demonstration Grant awarded to DriveOhio-led team by The U.S. Department of Transportation (USDOT). The purpose of the project is to evaluate ADS operation in rural areas. A variety of tests were conducted in controlled environment on two Ford Transit Vans (namely Van-1 and Van-2) equipped with ADS technology to help inform the Safety Management Plan (SMP) and driver training protocol for deployments on rural roads and to demonstrate safety of the proposed ADS.

This document provides the reader with:

- A brief overview of the ADS platform and the vehicles chosen for the ADS Demonstration Grant.
- The objectives of the CE testing.
- An overview of the CE tests conducted at TRC Inc.'s SMARTCenter facility.
- Key findings and results from the CE testing.
- The conclusions of the controlled environment testing.

TRC Inc. has conducted the CE testing at the Transportation Research Center Proving Grounds in East Liberty Ohio, with support from project partners. The results of the testing and evaluation informed the ADS Demonstration Grant team of the operational considerations, necessary safety procedures, and readiness for deployments and data collection on rural roads. Furthermore, the requirements of driver and ADS operator training for these specifically tested vehicle/ADS stack were finalized during testing. All of the information derived during the course of CE testing will be used to update the SMP and operator training protocol for deployments on public roads. Should future changes be made to the software and it is determined that it warrants further CE testing, this report may be updated.

2 Controlled Environment Testing Objective

There were two primary objectives of controlled environment testing that was performed by TRC Inc.:

1. System education and prove-out
2. System behavior extrapolation

The first objective of controlled environment testing was for the testing and research teams of TRC Inc. to educate themselves on the system that was tested and prove out the operational characteristics being tested. For any ADS that will eventually be deployed on public roads, it is important to test the expected operational challenges in a controlled and safe setting. The test results and findings could be extrapolated to get insight into how the system would behave in real-world setting. Hence, the controlled environment testing includes the following sub-objectives:

- Basic systems functionality training and prove out
  - The team must achieve mastery of the system to ensure that tests can be performed safely, reliably, and repeatedly. This means training test teams on the appropriate systems so that they have an understanding of how to operate the vehicles, as well as expected vehicle behavior across all potential scenarios. Systems and personnel are taken through a wide variety of testing scenarios to prove out systems operations and train the personnel on vehicle operations.
- Data recording development and prove out
  - As a requirement of testing, all data acquisition systems (DAQ) must be developed and deployed in a controlled environment to prove out operation prior to on road deployment. All necessary personnel need to be trained on all DAQs prior to on-road testing. This includes the prove out of the entire data transmission pipeline up to the point of data storage pending data processing.
  - The ADS vehicle used Cyber RT as the main backbone for transmission of data between the sensors, computer, and actuation. ("Apollo's Cyber RT is an open source, high performance runtime framework" designed specifically for Apollo [1]) This served as the main DAQ, as it allowed for a standardized collection of the data, where all the sensor data and control commands were collected in pre-determined messages. These messages were recorded and are able to be converted to other storage mediums in the future.
- Limit systems operations
  - It is necessary for test teams to test systems at operational limits. Since the vehicle operating at its operational limit during deployment could be safety critical, it is important for the test team to assess the vehicle operation at its limits. The CE testing allowed the test team members to understand where the operational limits are and how the vehicle responds prior to operational limits, once operational limits are reached, and as operational limits are exceeded.

An inherent limitation of any controlled environment testing is an understanding that only a small portion of the potential operational scenarios will be covered during controlled environment testing. This limitation necessitates that the subset of tests covered during controlled environment testing allow for the extrapolation of vehicle behavior to all scenarios that might be encountered on roadways. This is the second objective to be accomplished, taking the demonstrated behavior seen during the testing and extrapolating to potential failure modes that could be seen on roads. This extrapolation is primarily completed through root cause analyses,

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where the fundamental failure seen during failed tests is determined. With the failure cause properly determined, it is possible to extrapolate where additional failures might occur for the same reason.

3 Background

3.1 An Overview of the ADS System, Platform, and Vehicles

The following sections cover the ADS software, sensors, vehicle models, and test categories that are part of the controlled environment testing program. The ADS platform deployed for this phase of testing was a prototype Society of Automotive Engineers (SAE) L3 conditional automation system.

The ADS vehicle, a Ford Transit Van used for the testing program is outfitted with a Hexagon PACmod drive-by-wire kit, perception sensors, Spectra-2 computer for computation, and NovAtel GPS for localization. The main control software is based on Apollo, which is an opensource control stack. It provides a set of software subsystems such as localization, planning, perception, and control that make up the automation stack, as shown in Figure 1. To interface with driver-by-wire, AutonomoStuff's Speed and Steering Control (SCC) software is used. Apollo uses Dreamviewer as human machine interface (HMI) for feeding waypoints and live visualization of different signals. Figure 2 shows a view of this HMI visualizer.

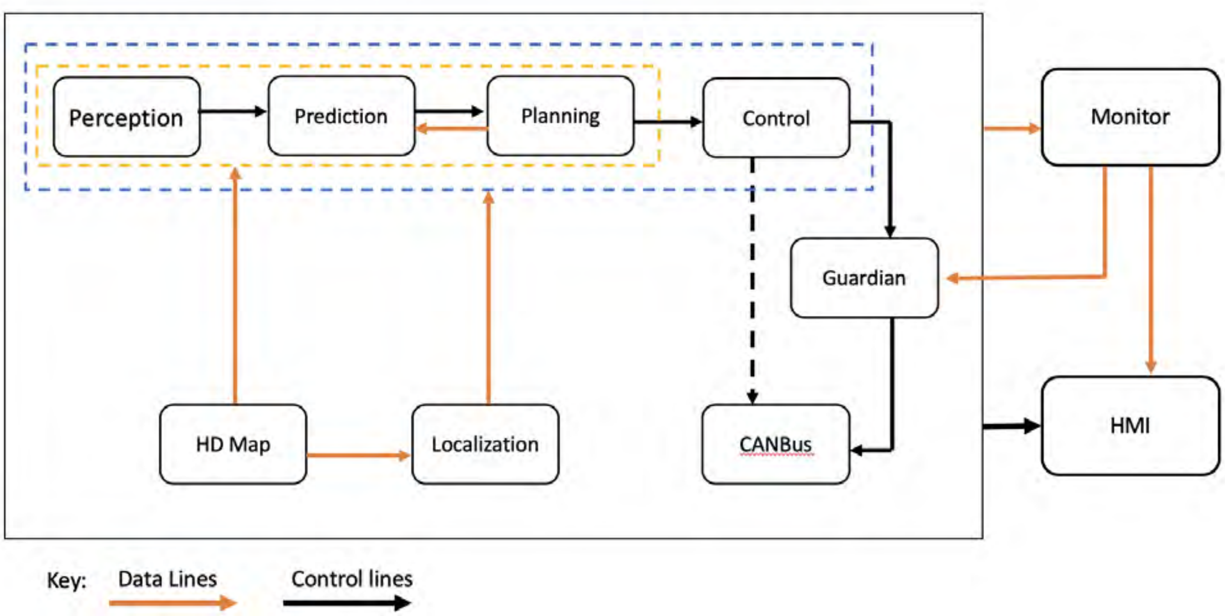

Figure 1. Software stack diagram of Apollo and the different sub-systems.

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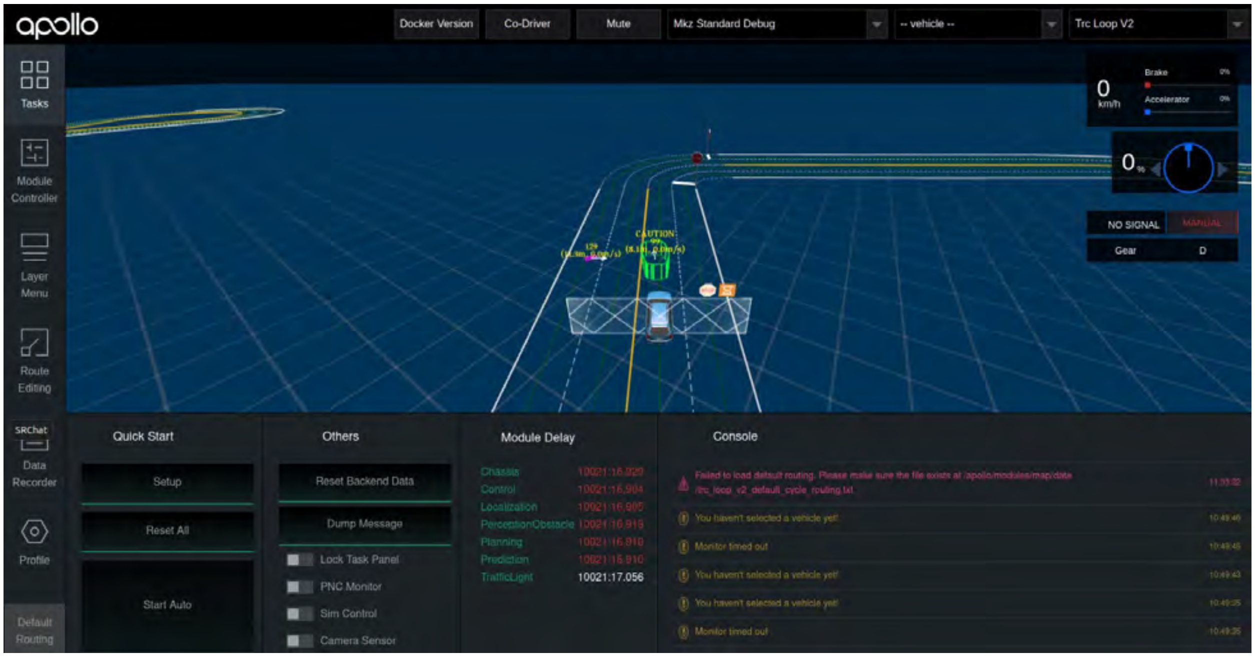

Figure 2. View of Apollo's Dreamviewer visualizer with obstacle detection

The vehicle is equipped with numerous sensors that are required by Apollo such as LIDAR, GNSS/INS sensor, and cameras. Table 1 below shows important characteristics of the equipment installed in the ADS. Figure 3 shows the architecture of the sensor suite installed on the vehicle.

Table 1: Summary of the hardware and software integrated into the ADS platform

Equipment	Specs
Computer	Spectra 2 Intel XEON E2278G 8th Gen 2.1/4.4GHz 8C | 12T, 80W TDP processor - 32GB DDR4-2666Mhz SODIMM (2X16GB) - (1) 256GB M.2 2280 Solid State Drive - Primary - (1) 1TB 2.5" SATA III Solid State Drive - (2) NVIDIA QuadroRTX-A4000 GPU - Supports dual RTX-A4000 - Supports 8th/9th-Gen Intel® Core™ i7/i5 LGA1151, Xeon® E - Up to 128GB ECC/ non-ECC DDR4 2133 (4x SODIMM)
Radar	Continental (ARS-408-21) Long Range Radar Sensor 77 GHz Premium
Lidars	1. Velodyne (VLP-32C-A) (front center) 2. Velodyne (VLP-16-A) (left) 3. Velodyne (VLP-16-A) (right) 4. Velodyne (VLP-16-A) (rear)

Equipment	Specs
GPS	NovAtel (NVL-KIT-LEVEL-2.5-OEM7-U) Includes: - 1x PwrPak7D-E2 dual antenna GNSS/INS enclosure containing OEM7720 with Epson G370N IMU. - GPS+GLO, L1/L2, - NovAtel CORRECT RT2+PPP+Single Point+DGPS PNT, - ALIGN Relative Positioning, - ALIGN Heading, - 20 Hz Data Output Rate, Raw Measurements, Interference Mitigation, SPAN + Land Profile, - Relative INS. - 2x Low profile, roof mount, dual-frequency GNSS antenna, L-Band, TNC female connector
V2X	Cohda Mk5 OBU
Control	AutonomoStuff Speed and Steering Control
Cameras	1. Leopard Imaging Inc. (LEP-LI-USB30-AR023ZWDR-6): 1080p WDR USB 3.0 Camera, Active pixel: 1928H x 1088V, Frame rate: 30fps, Pixel size: 3x3um, 6mm lens 2. Leopard Imaging Inc. (LI-USB30-AR023ZWDRB-12) USB 3.0, 12mm lens
RTK corrections	Cradlepoint: CPI-DOME-AN dome antenna, IBR-900 Router
Perception Stack	Apollo V5 • Localization module realized using GNSS with RTK • Primary perception module via lidar based object detection • Tracking and prediction module • Dynamic path planning module • Routing module plans the driving route which feeds the planning module. • Control module which defines velocity and angle of vehicle. • Live traffic operation using GNSS based localization on an AS approved route. • AutonomouStuff guarantees basic localization
Drive by wire	Hexagon PACMod Throttle & brake by-wire controller module, steering & shifting by-wire controller module

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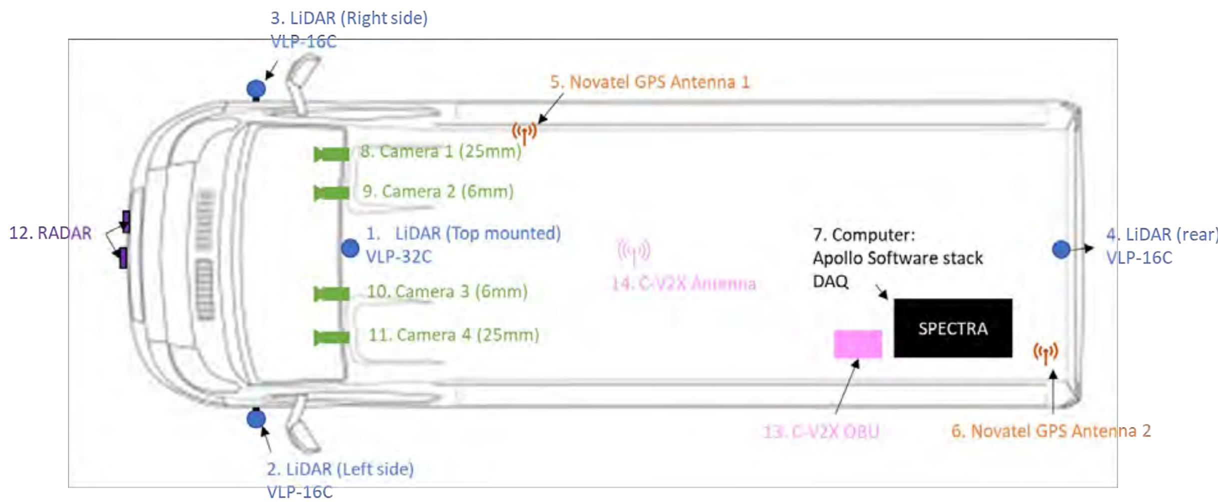

Figure 3: Schematic diagram of the sensor suite on the Ford Transit van

3.2 Alignment with Passenger Vehicle Concept of Operations

The CE test plan used information presented in the Passenger Vehicle Concept of Operations (ConOps) to build out a test plan based on outlined user needs. The project team's knowledge of the ADS stack (Apollo) and ADS vehicle platform was also used to refine user expectations, when necessary. This test plan excluded test scenarios in select cases where the ConOps documents a user need, but the documentation specified the ADS stack could not satisfy. In the future, should that capability be developed, or a different software stack be chosen that has that capability, CE testing for the added capabilities will need to be conducted separately.

The CE test plan focusses on the following use cases and operational scenarios listed in the Passenger Vehicle ConOps:

- Use Case 1, Scenario 1 (UC1-S1) – Single Vehicle Automated Driving – ADS
- Use Case 4, Scenario 1 (UC4-S1) – Intersection Navigation

3.3 ADS Stack Desired Capabilities

Based on these high-level use cases, a list of desired capabilities of the ADS stack were prepared and were listed in the passenger vehicle ConOps document. The CE test plan is prepared to better understand and/or validate the capabilities and limitations.

3.4 Controlled Environment Test Scheme

The CE testing took a phased and categorical approach towards developing an understanding of the ADS-equipped vehicle's capabilities to operate safely on public roads. The scheme was structured to expose the ADS-equipped vehicle to progressively complex situations, test the ADS's response, and inform the safety operator of expected system behavior. This evaluation

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assessed knowledge gaps, functionality gaps, and increased the safety operator's confidence prior to Deployment One in southeast Ohio. Figure 4 shows an overview of the testing scheme.

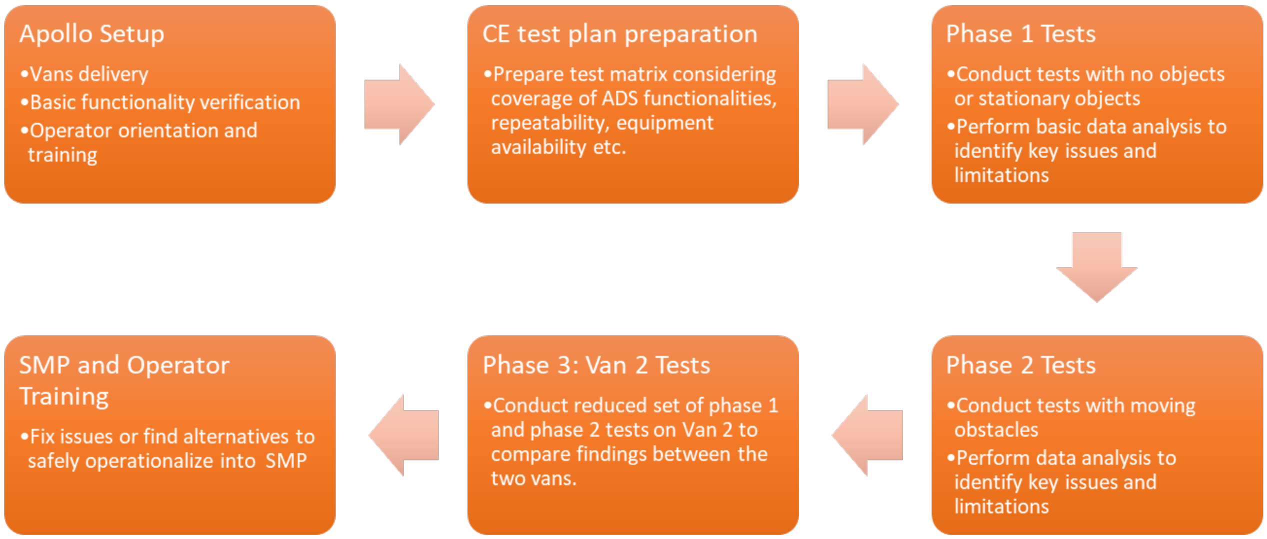

Figure 4. Flow chart of test plan development and implementation.

The first step was to receive the delivery of the vans and high-definition maps of the TRC Inc. SMARTCenter. Hexagon, the ADS technology integrator for this project, provided training, performed basic calibrations, and demonstrated essential functionality. This included introduction to the hardware, Apollo startup, DreamViewer interface, creating routing requests, engaging and disengaging into/from autonomous mode, data logging, basic troubleshooting, etc. TRC Inc. conducted tests to ensure basic functionality e.g. traffic light detection, straight and curved road driving, driving around obstacles etc. to understand the system functionality and limitations. Some functional issues were identified e.g. the spectra computer accumulates log files and gradually consumes significant memory on the hard-drive eventually resulting into slowdown and complete Apollo failure. Such issues were fixed or operationalized with the help from Hexagon. As TRC Inc. learned about the system and gained experience with its operation, a test plan was developed considering all the desired functionalities of the system and expected scenarios during on-road deployment on the chosen routes in southeast Ohio.

Since the team has two systems with same technical specifications, all the tests were first conducted only on Van 1. The Van 1 CE test execution schedule was divided into two phases. Phase 1 considered driving with no obstacles or driving with stationary obstacles. The main goal of Phase 1 was to validate localization accuracy, route planning capability, vehicle response to Traffic Control Devices (TCD), driving capability at intersections, and stationary obstacle detection and avoidance. The Phase 1 revealed some limitations of the Apollo software and hardware e.g. the object detection distance. In Phase 2, the vehicle's capability to operate in the

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dynamic traffic was evaluated. The limitations identified in Phase 1 informed the test plan for Phase 2. After Van 1 went through both the phases of testing, Van 2 was tested to confirm operational similarity between the two systems and identify any key differences. For Van 2 tests, similar tests were removed from Phase 1 and Phase 2 routine, and the number of repetitions were reduced. Vehicle data, ADS data, and notes from test engineers were collected for each test and used for data analysis. The reviews and notes from the test engineers supported by the data analysis resulted into better understanding of the safe operation domain of the systems. Finally, this understanding was used to inform SMP and operator training documents.

3.5 Data Collected During Tests

Three types of data were collected for each test – 1) vehicle and ADS data from the vehicle, 2) test engineers' reviews and notes, 3) data from peripherals like traffic light status, obstacle positions, HD map etc. Apollo allows logging various data channels in a cyberbag (.record) format.

4 Test Requirements

Testing requirements for each test were defined in the Controlled Environment Test Plan published prior to Controlled Environment Testing. Generally speaking, tests were completed in fair weather conditions defined by:

- Temperatures ranging from 32°F and 80°F.
- Wind not exceeding 25 mph (11.2 m/s).
- High visibility during daylight operating hours.
- There was no testing during inclement weather.

Additionally, testing was completed under ideal roadway conditions with:

- Well-defined lane markings.
- Lane widths between 3.35 to 4.57 m (11.0 to 15.0 ft).
- Well defined roadway edge.
- Strikeable targets that were easily visible.
- Manually driven roadway traffic that was easily visible.
- Generally, no roadway visibility obstructions.

Prior to testing, AutonomouStuff trained TRC in the calibration procedures required for the ADS. This included the intrinsic and extrinsic matrices required by the camera and LIDAR that the system employed. TRC Inc. employed the matrices calculated during the training period throughout the entirety of the controlled environment testing. As a part of the testing, TRC Inc. would occasionally vary some of the ADS calibration parameters to determine if altering these

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parameters would result in a different test outcome. However, the majority of testing was completed with the calibration parameters in their default state.

An overview of the instrumentation used for the tests described in this document is provided in Table 2.

Table 2. Test Equipment

Type	Output	Range	Accuracy
Tire Pressure Gauge	Vehicle Tire Pressure	0-150 psi	±0.5% of applied pressure
Platform Scales	Vehicle Total, Wheel, and Axle Load	0-20000 lb per each axle	±1.0% of applied load
GPS Speed Sensor	SV and ME(s) speed	0.1-80 mph (0-35.8 m/s)	+/- 0.25% of full scale range
Multi-Axis Inertia Measurement Unit	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm
	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%
Data Acquisition System [Amplify, Anti-Alias, and Digitize]	Record Time; Velocity; Distance; Lateral, Longitudinal, and Vertical Accelerations; Roll, Yaw, and Pitch Rates; Steering Wheel Angle.	Sufficient to meet or exceed individual sensors	Sufficient to meet or exceed individual sensors
Data Flag	Signal from SV representing message to driver if presented	0 – 10V	Output response better than 10 ms
Vehicle Dimensional Measurements	Location of GPS antennas; Vehicles Polygon measurements.	N/A	0.04 in (1 mm)
Real-Time calculation of position and	Distance and Velocity to lane and Emb	Lat Lane Dist: ±30 m	±2 cm
		Lat Lane Vel: ±20 m/sec	±0.02 m/sec

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Type	Output	Range	Accuracy
velocity relative to lane and Emb		Long Range to Emb: ±200 m	±3 cm
		Long Range Rate: ±50 m/sec	±0.02 m/sec
Robotic Platform with Multi-Axis Inertia Measurement Unit	Position	Latitude: ±90 deg Longitude: ±180 deg	Position: ±2cm
	Longitudinal, Lateral, and Vertical Acceleration	Acceleration: ±100 m/s^2	Acceleration: 0.1%
	Roll, Yaw, and Pitch Rate	Angular Rate: ±100°/s	Angular Rate: 0.04%

5 Phase 1 CE Testing

The focus of Phase 1 of CE testing was to subject Van 1 to broad spectrum of tests covering basic driving features listed in Table 3. Same set of tests were used to test multiple features. For example, obstacle detection and obstacle avoidance are incorporated under stationary obstacles. Traffic light and stop sign detection and driving at intersection are combined into 'driving at intersection' tests.

Table 3: ADS features tested in Phase 1

1. General Driving	
Waypoint following (Curved roads)	Route selection following
Waypoint following (straight)	Enable ADS at speed
2. Driving At Intersection	
Traffic lights at signalized intersection	Stop signs
Turn left	Turn right
Straight	
3. Lane Changing	
Straight road	Curved road
4. Stationary Obstacles (Detection and Avoidance)	
Vehicle	Pedestrian
Bicycle	Motorcycle
Large objects (e.g. trailer)	Child pedestrian

For each of the four broad categories in Table 3, test parameters and their intended values were identified; for example, speed, turn type etc. For CE testing, the team developed a reduced test

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matrix instead of full factorial Design of Experiments. The reduction of tests was done based on the requirements and ADS feature under test.

5.1 General Driving

The first step to validate the capabilities of the system was to test the basic functions like engagement, disengagement, path planning, path following, and lane changes in absence of obstacles. During training with Hexagon, the team had learned when and how to engage the system into autonomous mode or different options to take the control over to human driver. Engaging the vehicle into autonomous mode when stopped was tested multiple times during the training as well as CE testing. It was observed that the system is able to engage safely when the vehicle is on the map and is receiving positioning information from GPS. Hence, for general driving CE testing, following goals were set:

1. Engagement at speed
2. Path planning and following with no obstacles
3. Lane change on straight and curved roads

The test schedule for general driving testing was divided into 3 sets, one for each goal. Test matrix and results for each are described below.

5.1.1 Engagement at speed

During public road deployment, the ADS platform or the driver may need to disengage from autonomous driving mode while driving on the road. Depending on the traffic conditions, the operator may decide to re-engage into autonomous mode while driving at speed. Hence, the main purpose of these tests was to ensure that the system can be engaged safely at non-zero speeds. Tests were performed on a straight road with no lane changes required in the planned route. These tests indicated that the system was safely able to engage into autonomous mode, re-plan and complete the route. However, when lane change is required on the same road segment, the system exhibited high steering rates and high lateral acceleration after engaging at speed. Hence, more tests were conducted with different engagement time and space available for lane change after engagement.

Test Matrix

The different tests are shown in Figure 5 in which the red circles indicate waypoints given at the time of route planning, blue triangles indicate location of engagement into autonomous mode and the blue line shows actual trajectory on the maps. The vehicle path is from left to right. In runs 1 and 2, the system was engaged at the beginning of the route, whereas in other runs, the system was engaged at different distances from upcoming waypoints.

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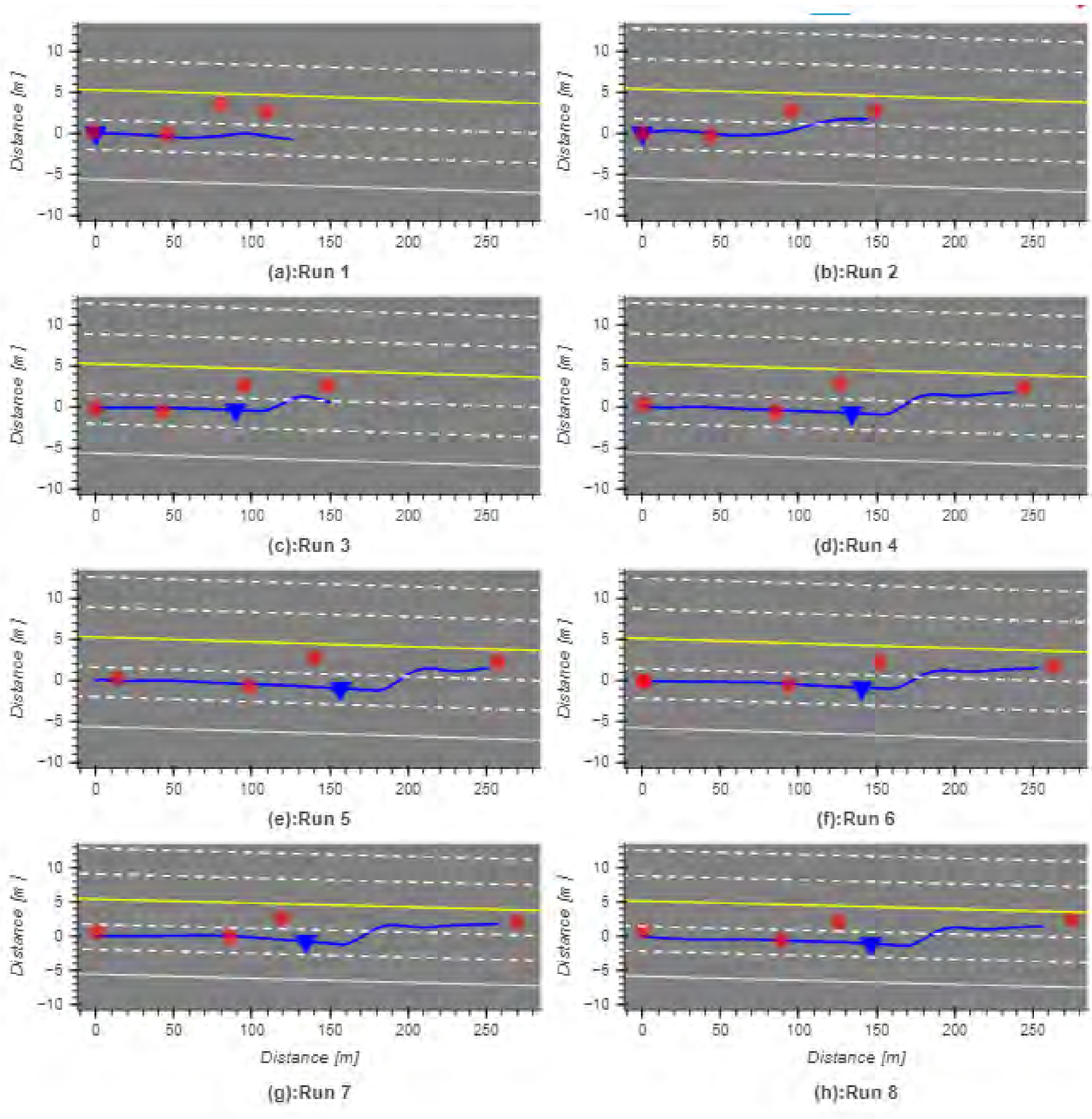

Figure 5: Waypoints and engagement locations during different tests conducted for assessing engagement at speed.

Results

In runs 1 and 3 the system failed to reach the final destination and disengaged. This behavior was not repeatable and hence the root-cause could not be identified. Different data elements like steering angle, heading angle, yaw rate and lateral acceleration for all the 8 runs are shown in Figure 6. Only the results from runs 5-8 are shown in this report as runs 1 and 2 failed and 3 and 4 showed similar behavior as runs 5-8. The dashed lines in frame (a) indicate the engagement event. The data is shown from start of data logging till the system is disengaged.

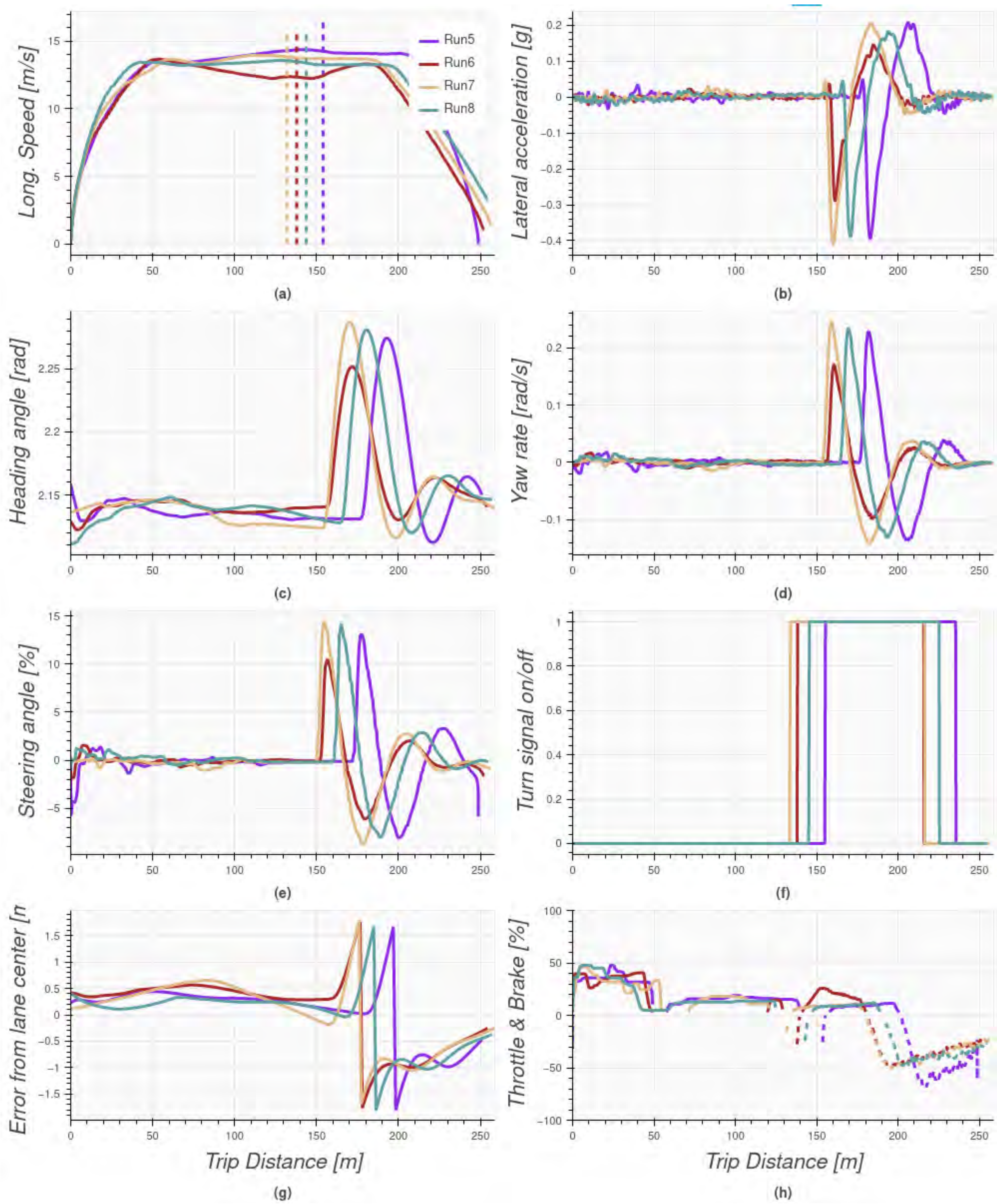

Figure 6: Results from engagement at speed test runs 5-8.

From Figure 6, frame (e) it can be seen that high steering angle was applied after engagement which led to approximately 0.4g of lateral acceleration, which is 10 times more as compared to the lateral acceleration observed during a typical lane change in autonomous mode. It was

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noticed during the data analysis that the planning and routing module does not update the desired trajectory for approximately 0.8s immediately after engagement as shown in Figure 7. It is likely that this delay results into larger error which intern results into higher steering control command. However, further investigation is required to resolve the issue.

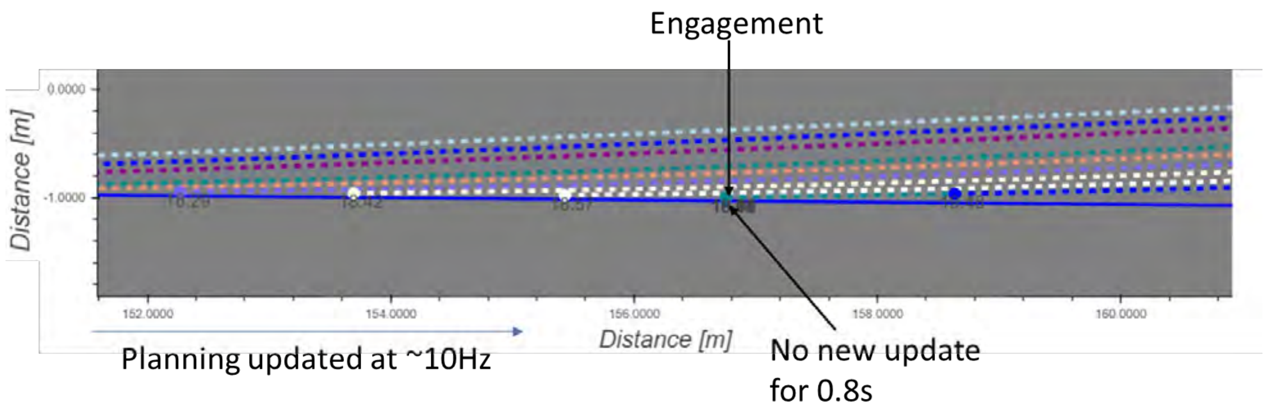

Figure 7: Path planning at the time of engagement

5.1.2 Path planning and following

Test Matrix

To test the path planning and following capability, a route was selected at TRC SMARTCenter with turns, stop signs, traffic lights, and lane changes. The desired route was entered into the system using Dreamviewer. Eight waypoints were used. After the planning was successful, the system was engaged into autonomous mode to test path following.

Results

The waypoints are shown in Figure 8 using red circles. The blue line indicates GPS position of the vehicle driving in autonomous mode. It can be observed that the system was able to track the waypoints.

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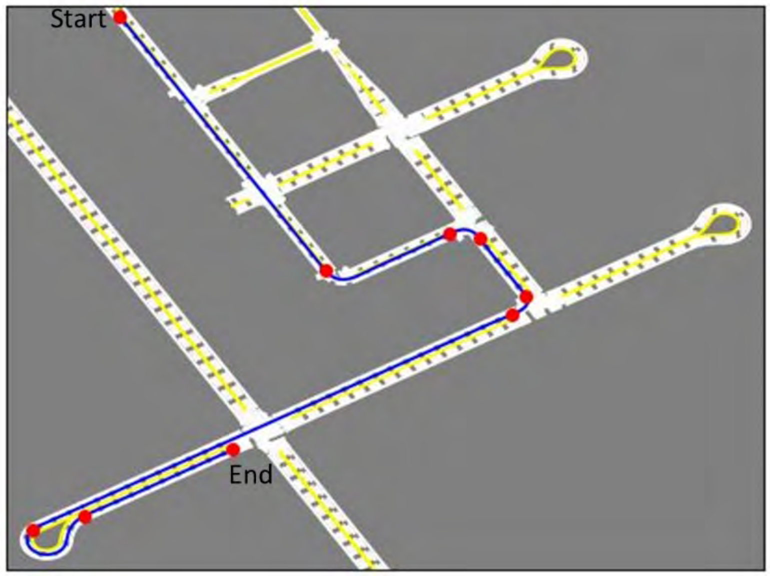

Figure 8: Complex route planning and following.

The driver and the operator did not notice unusual behavior during the autonomous driving. The system was able to stop at the stop sign and traffic light. It slowed down on turns as intended and stayed below or at speed limits throughout the trip. Figure 9 shows speed profile of the vehicle during this drive along the route.

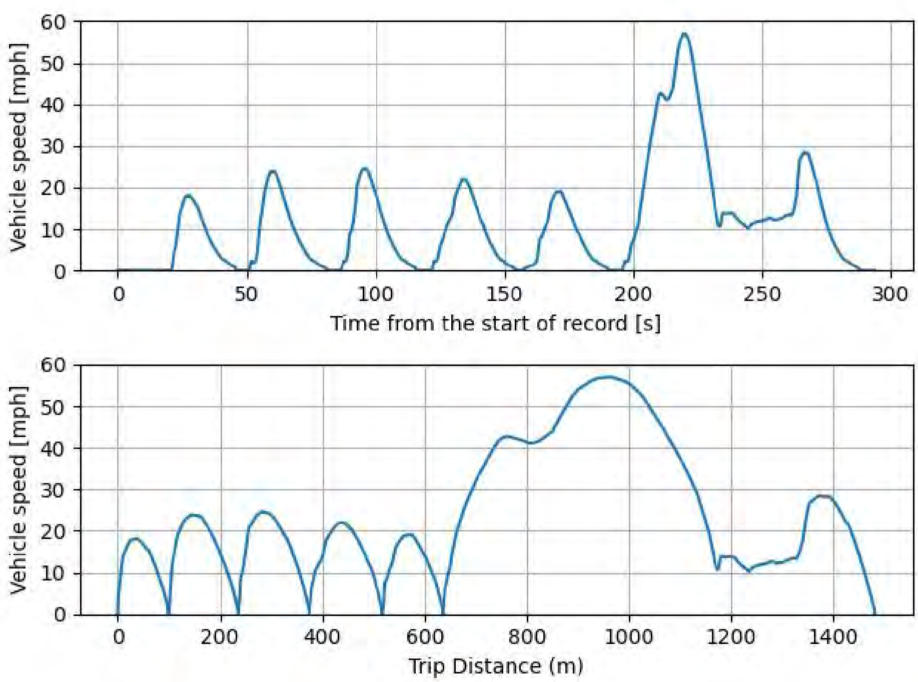

Figure 9: Speed trace of the autonomous mode drive

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5.1.3 Lane Change

Test Matrix

The lane changing capability depends on left vs right lane change, multi-lane lane changes and changing lanes on a curve. A 3-lane straight road segment and a 2-lane curved road segment were used for testing. For straight road, middle (M), left (L) and right (R) lanes were used and various combinations of making lane change were tested. For curved road, left curve and right curve were used to ensure the performance on left and right curves. *Table 4* shows the test matrix for lane change maneuver. Note that this is not a full factorial design as some of the combinations are duplicates. For example, middle lane to right lane is same as left lane to middle lane.

Table 4: Lane change maneuver test matrix

Test Parameters	Lane Change							
Curve	Straight				Left		Right	
Start lane	M		R	L	R	L	R	L
End lane	L	R	L	R	L	R	L	R

Results Single Lane Change

The important criteria for lane change include error from the lane center, yaw rate during lane change, and double lane change.

<u>*Left lane change:*</u>

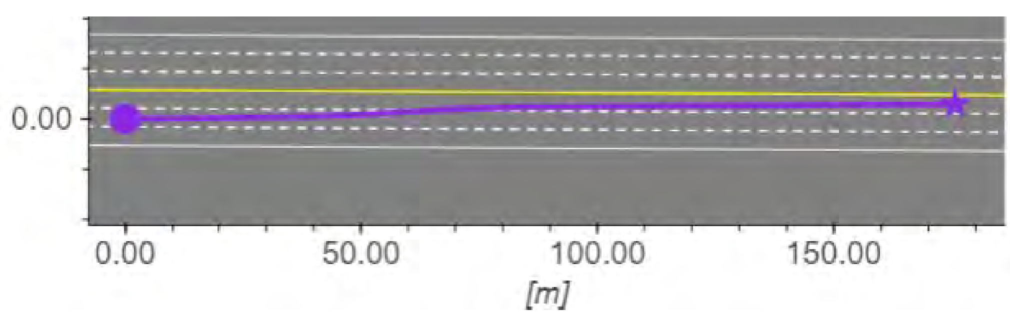

Figure 10: Left lane change GPS position of the vehicle on HD map.

Figure 10 shows GPS coordinates of the vehicle plotted on the HD map along with the planned trajectories. The filled circle marker indicates the start and a star marker indicates the end of the planned trajectory. It can be seen that the vehicle reaches center of the left lane after making lane change. During the trip, the system first plans a straight trajectory and then immediately starts planning for lane change.

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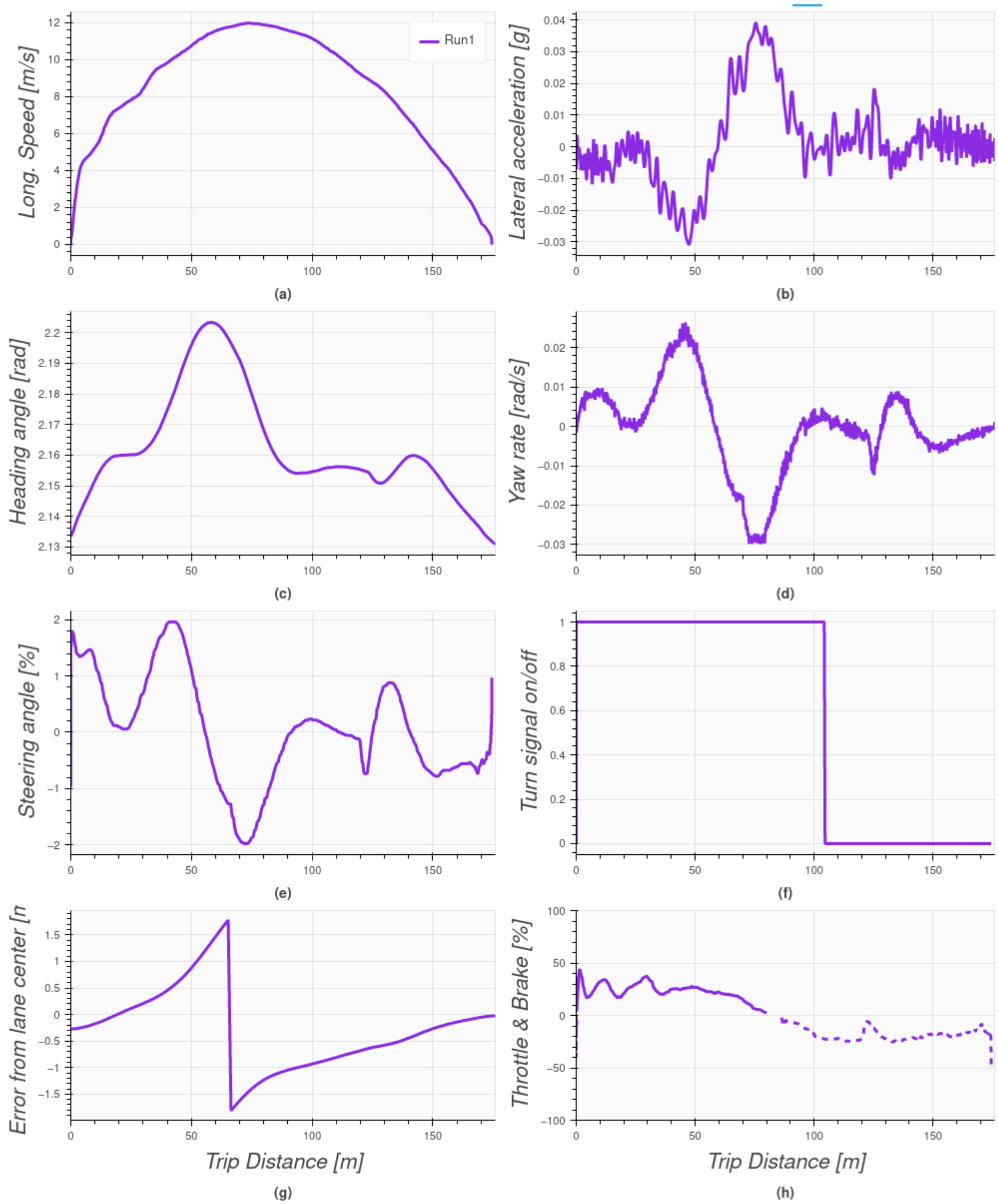

Figure 11: Left Lane change driving data

Figure 11 shows various vehicle dynamics data to assess the lane change maneuver. The steering angle plot in frame (e) shows that the system starts making lane change as soon as it is engaged at zero speed. Similarly, when the vehicle comes to a stop, there is high steering angle and fails to go to zero steering at stop. The lateral acceleration remains less than 0.04g as shown in frame (b). The right bottom plot (frame (h)) indicates that the system turned on the left turn indicator as soon as the system was engaged in autonomous mode. The error from lane center in frame (g) confirms that the system was able to achieve acceptable lane centering accuracy at the end of a lane change. This error is measured with respect to the HD map and not with respect to the physical lane line markings, i.e. the errors between HD map and physical lane line markings are not accounted in this computation. Results for right lane change indicated similar behavior as left lane change. Hence the results are not shown separately in this report.

Multi-Lane Change

Experiments of changing multiple lanes from left to right and right to left were conducted to ensure that the system is capable of making successive lane changes. During the right to left lane change experiment, the operators observed random disengagements. These unexpected events could not be reproduced consistently; hence, the disengagements could not be diagnosed. However, due to this unexpected behavior, the same experiments were repeated at two different longitudinal speeds – 50mph and 35mph.

Right Double Lane Change:

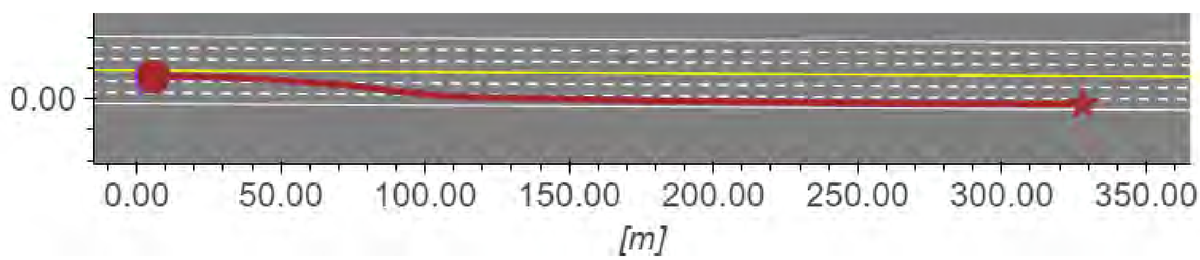

Figure 12: Double left right change: vehicle actual trajectory and planned trajectories on the HD map

Figure 12 shows the vehicle trajectory along with the planned trajectories during the tests. Where start of the trajectory is indicated by a filled circle and star indicates end of the trip. The most important thing to observe is that the system does not stay in the middle lane but performs a continuous double lane change.

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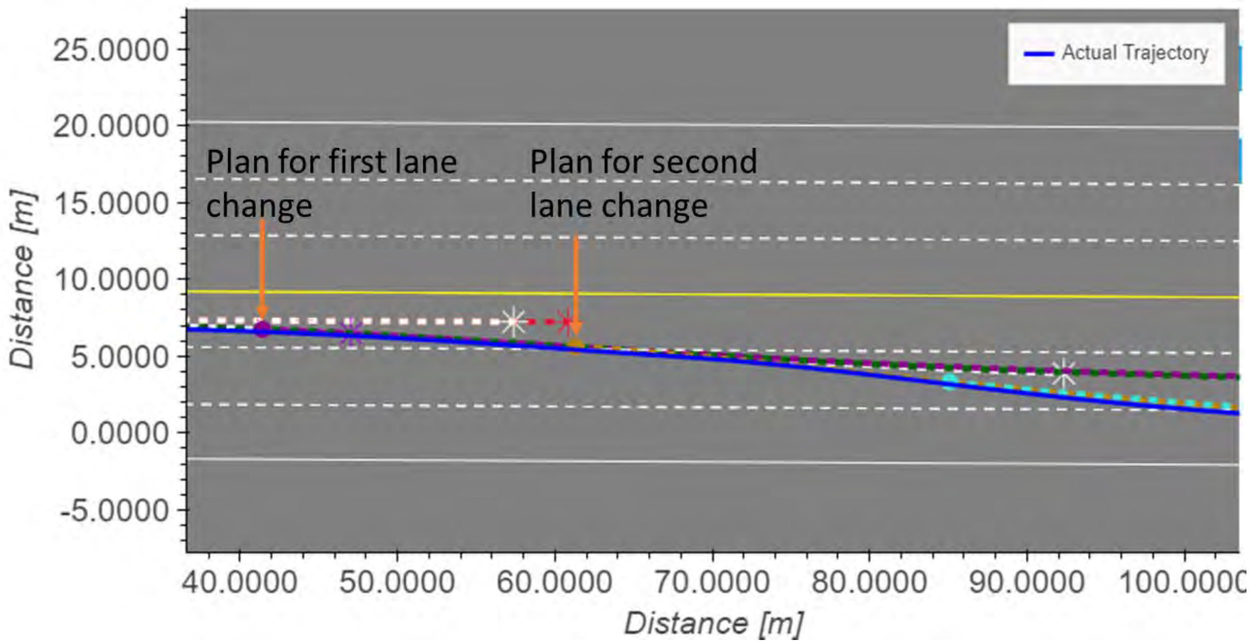

Figure 13: Planned trajectories during double right lane change

As shown in Figure 13, the system starts planning for the second lane change one time-step before it enters the middle lane. In the absence of secondary objects on the road, this behavior is not safety critical.

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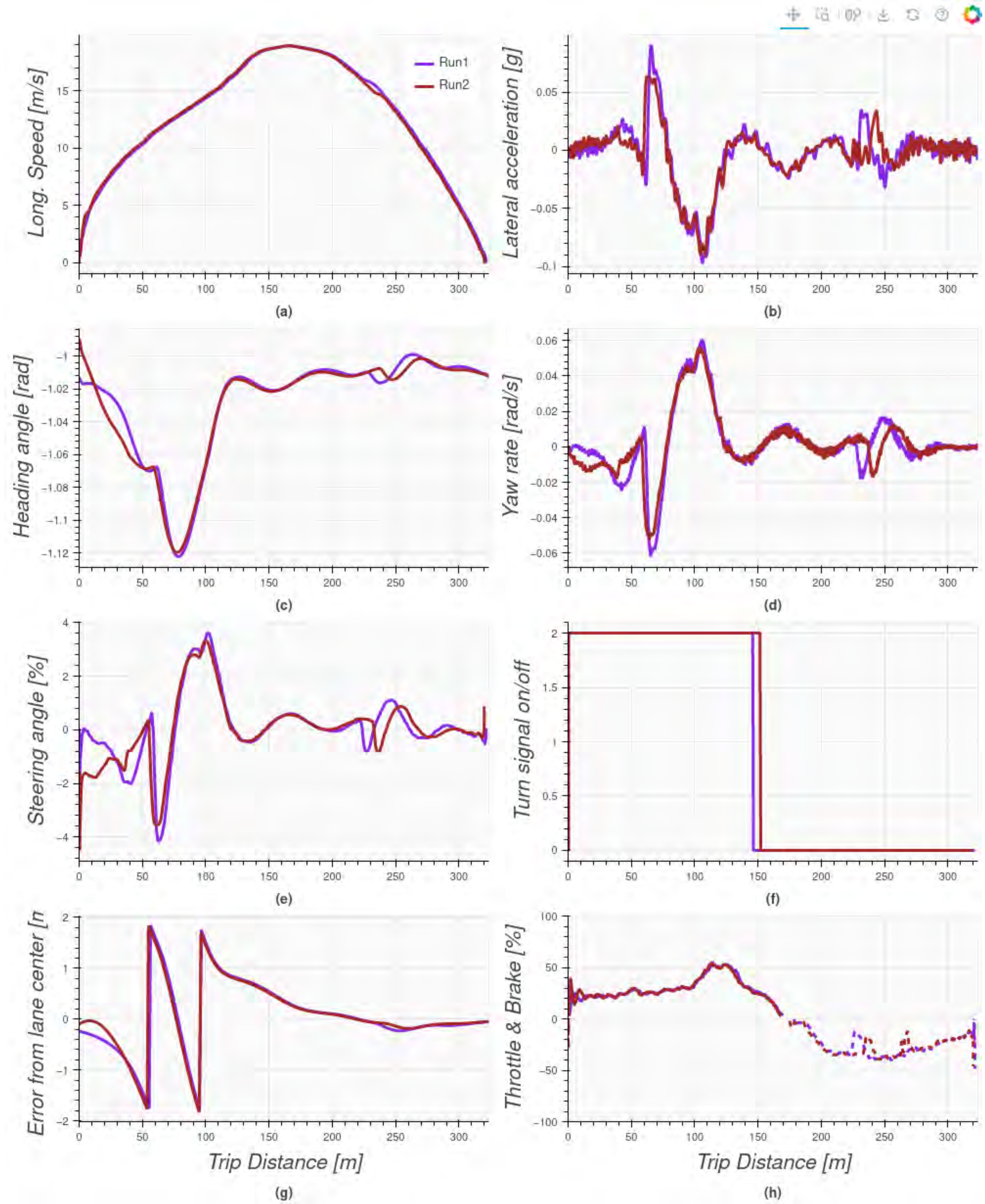

Figure 14: Vehicle driving data for double left lane change.

Figure 14 shows plots of various data obtained during the double lane change maneuver. Notably, unlike single lane change, a small overshoot is observed after successfully completing

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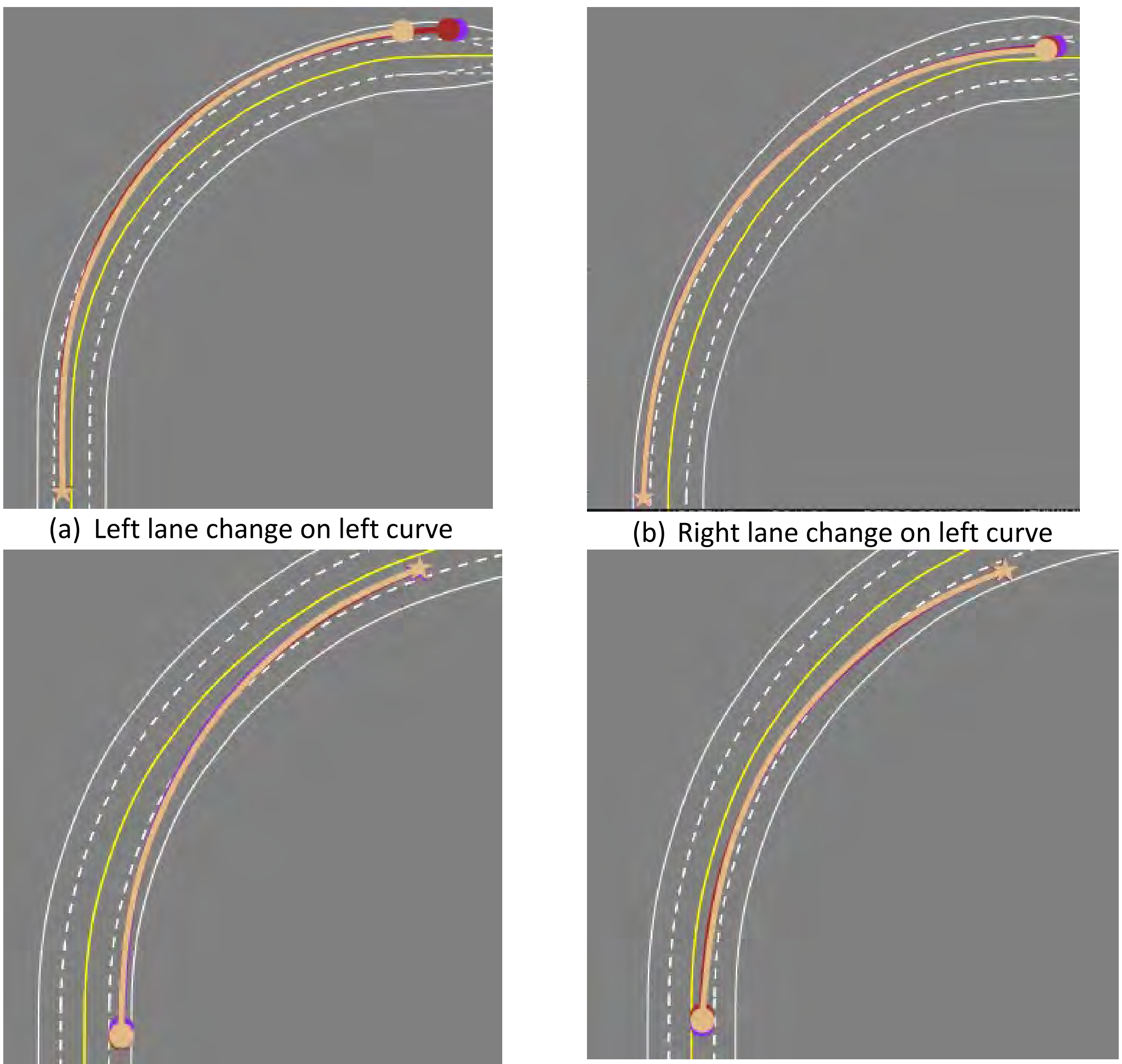
the double lane change as can be seen in frame (g). This behavior is consistent in both the tests. Similar to the single lane change, the system applies high steering angle at low speeds, specifically at the end of the trip. Similar behavior was observed from the results for left double lane change. Only once out of 3 tests, the system disengaged after completing the two lane changes. The reasons behind this disengagement could not be identified. The detailed plots for left double lane change are not shown in this report.

Lane Change on Curved Road:

Single left-side and right-side lane changes were tested on left and right curved road segment at SMARTCenter. The four test scenarios executed are shown in Figure 15. The filled circle indicates starting point and a star indicates ending point of the route.



(a) Left lane change on left curve

(b) Right lane change on left curve

(c) Left lane change on right curve

(d) Right lane change on right curve

Figure 15: Test scenarios for lane changes on curves

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Similar observations were made from all the four scenario executions. Hence, detailed results are shown for the scenario of driving on a right curved road and changing lane to left (frame (c)).

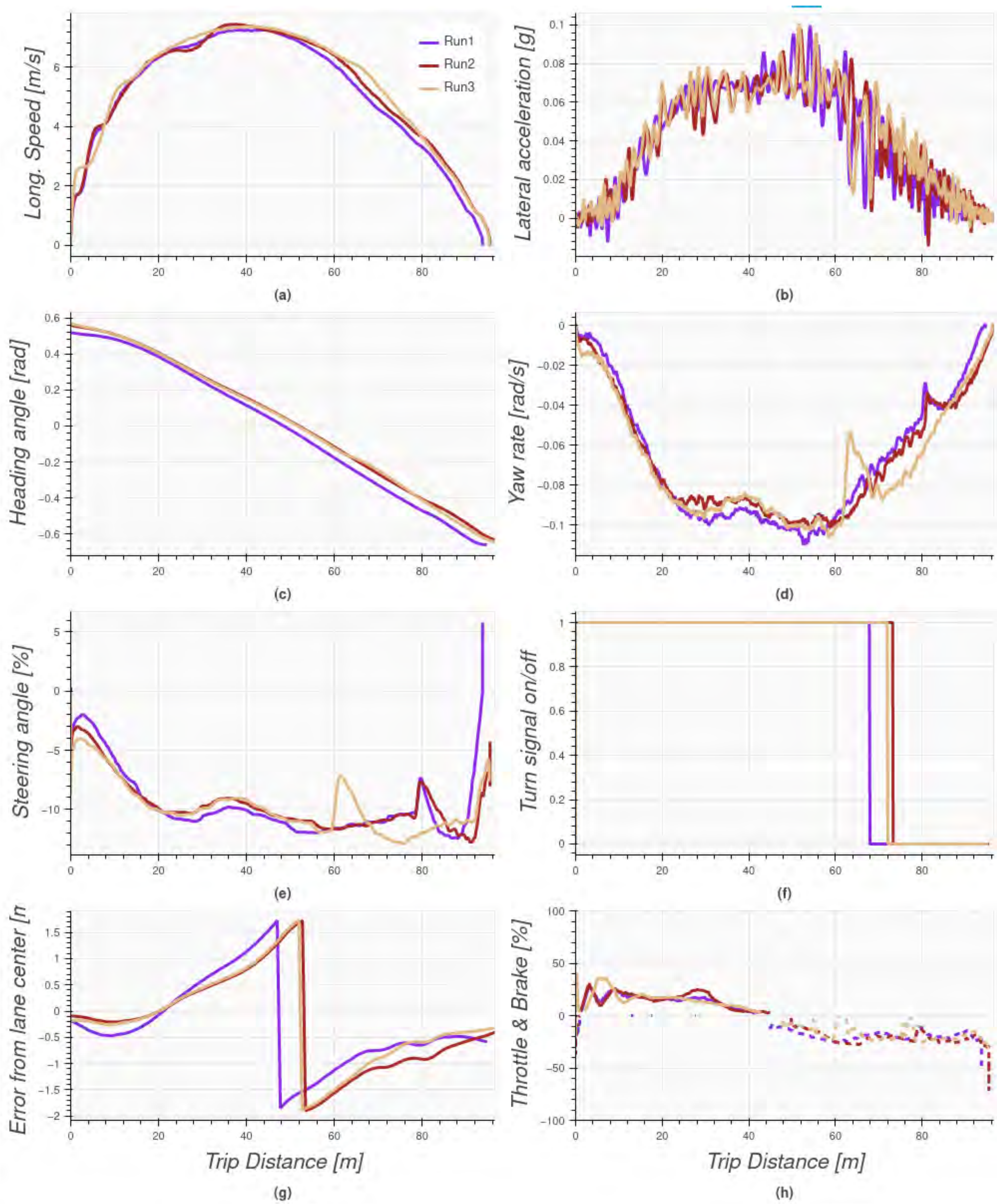

Figure 16: Driving data from curved road lane change test.

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Some critical observations were made after reviewing the data. The steering angle at the end of the run 1 was very high. The system applied brakes with magnitude of less than 1% while also commanding positive throttle as exemplified in Figure 17 where the dotted lines are brake percentage and solid lines indicate commanded throttle percentage.

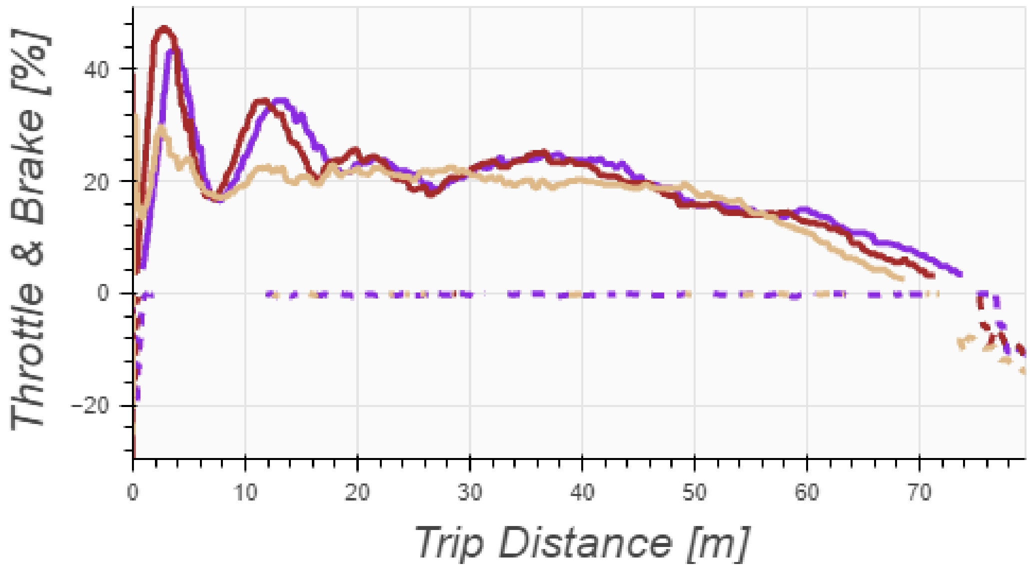

Figure 17: Example of Throttle and Brake % for lane change on curved road. The dotted lines are brake pedal positions and solid lines are accelerator pedal position.

In general, the system could keep the vehicle close to the lane center and make a smooth lane change with lateral acceleration acceptable for the drivers. In the case of left lane change on left turn scenario, the system turned on right turn signal initially and then switched to the left turn signal as can be seen in Figure 18. This was noticed inconsistently during testing and will be monitored by the operators to ensure minimal impact to surrounding traffic during deployments.

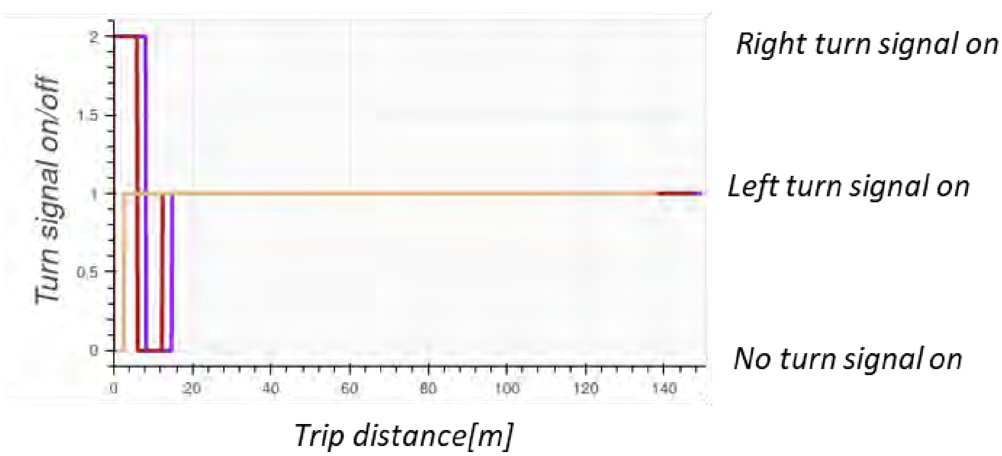

Figure 18: Turn signal during left lane change

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5.1.4 Key Conclusions

The following main conclusion are drawn from the data analysis results and operator observations.

In absence of secondary obstacles, the ADS platform is capable of:

1. Planning, routing, and following waypoints.
2. Engaging into autonomous mode at zero speed or on straight road segments with no lane changes expected on the same segment.
3. Detecting stop signs, traffic lights and maneuvering at intersections according to the traffic control devices.
4. Driving at the center of the lane.
5. Making single and double lane changes on straight and curved road segments.

However, the ADS platform has some drawbacks.

1. Engaging the ADS platform at higher speed, when a lane change is required on the same road segment, results in an undesirable steering control input and lateral acceleration. This should be preemptively avoided by the operators.
2. The ADS platform does not consistently use the correct turn signals.
3. Occasionally, the controller commands brake and accelerator at the same time.

5.2 Driving at Intersection

For CE testing of the system's behavior at intersections, TRC Inc. used two intersection types – signalized intersection and stop sign intersection. The main goal was to validate following system capabilities:

1. Stop sign detection
2. Traffic light detection
3. Driving according to the control device

Note that navigating at intersection in presence of traffic was out of the scope from these tests. This added complexity was included in the Phase -2 CE testing.

5.2.1 Test Matrix

Navigating around an intersection in absence of surrounding traffic involves driving towards the intersection at a set speed, detecting the intersection, identifying the traffic light for the lane, and according to the traffic light phase follow the pre-planned path, which could be turn left, right, or straight. The team decided to start testing at higher speed assuming that if the system operates as intended at higher speeds, it also operates at lower speeds. The traffic light

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intersection at the TRC SMARTCenter has 3 lanes – Left (L), Right (R) and Middle (M). The stop sign intersection at the TRC SMARTCenter has 2 lanes - Left (L) and right (R). Hence, the three independent variables are described below.

1. Turn type: Straight, Left, or Right
2. Intersection/signal type: Stop sign(S), green (G), Red (R), Yellow (Y)
3. Start lane: Left (L), Right (R) and Middle (M).

Instead of doing a full factorial design, the team reduced some tests due to similarities with other tests or infeasibilities. For example, turning left from right lane is not allowed and vice versa (Apollo makes lane change appropriately before approaching the intersection). The resulting test matrix is given in Table 5. Each test was repeated 3 times.

Table 5: Test matrix for Driving at Intersection

Test Parameters	Driving at Intersection												
Speed Limit	35-55												
Turn type	Straight					Left				Right			
Intersection/Signal	S		R	G	Y	S	R	G	Y	S	R	G	Y
Start Lane	L	R	M	M	M	L	L	L	L	R	R	R	R

5.2.2 Results

Stop Sign:

Left turn, right turn, and straight pass at intersection with a stop sign were tested. For the straight pass test, two different speeds and two different lanes were used. The four scenarios are depicted in Figure 19. The plots show the vehicle trajectory plotted on the HD map. Filled circles indicate start of the trajectory and star indicates end of the trajectory.

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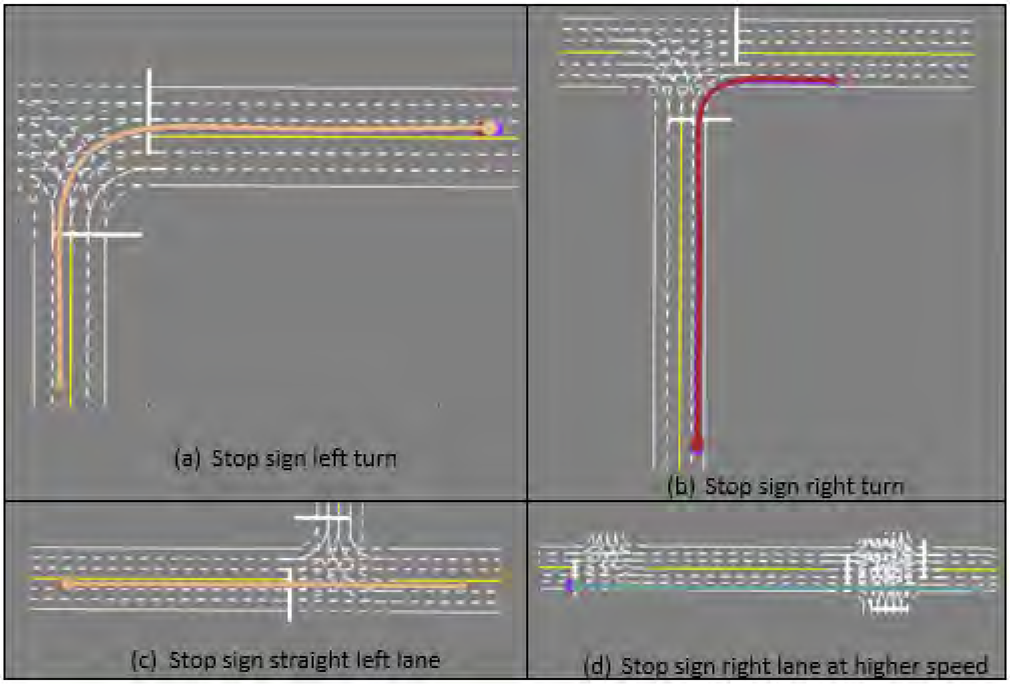

Figure 19: Stop sign intersection testing scenarios.

It was observed that the system drives the vehicle closer to the left (right) side on left (right) turn (refer Figure 20). In Figure 21, frame (g), lane centering error is plotted. The maximum error from lane center is approximately 0.8m. This observation is important as the places where lane width is narrow, this drift could become a safety concern.

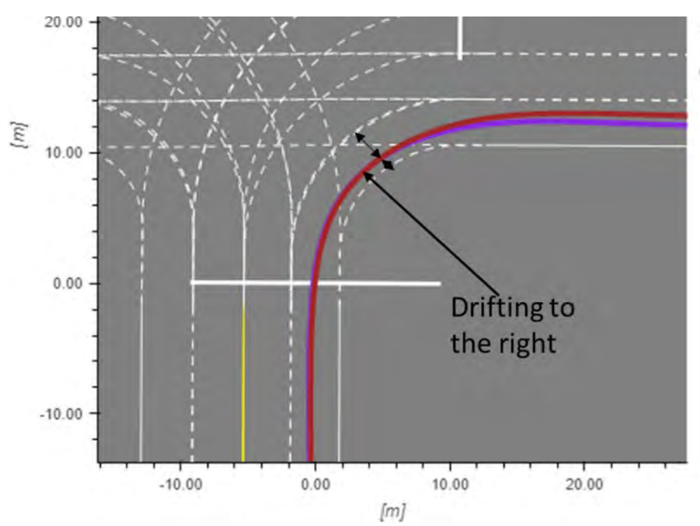

Figure 20: Stop sign intersection – vehicle drift from lane center at turn.

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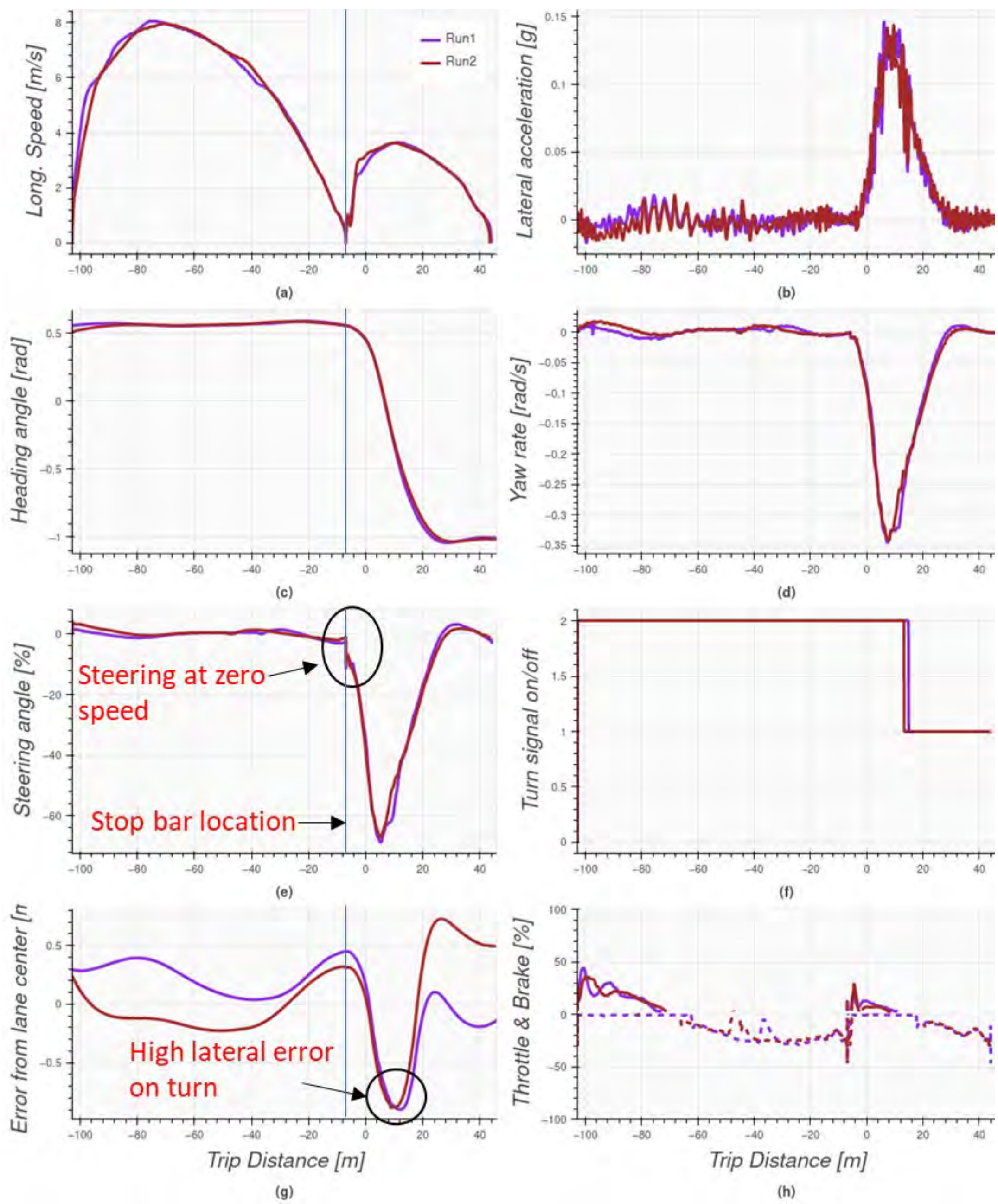

Figure 21: Key results from right turn at stop sign test.

Figure 21 shows plots of key data elements from the right turn tests. In these plots, the stop sign location is at zero distance. Generally, the system was able to detect the stop sign in the HD map during all the tests. It stopped approximately 7 m before the stop sign, waited for a fixed time and accelerated again. The system was able to correctly command the turn-signals during all the tests. However, the system was unable to drive at the center of the lane during turns. Note that the error from lane center is approximately 0.9 m as can be seen from frame (g). The undesirable

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behavior of applying brake and throttle at the same time was also observed in some tests. As observed in other tests, at low speeds there is unexpected steering.

Traffic Light:

The traffic light perception system uses two cameras (wide angle and zoom) to detect traffic light color for the lane. During calibration process, it was found that the system is very sensitive to the position and orientation of the cameras. Even after calibration, the traffic light system failed to correctly detect the traffic light for the lane, particularly from longer distance. Hence, the main purpose of these tests was to validate system's response to the traffic light assuming the traffic light is detected correctly. To minimize the uncertainty due to traffic light detection algorithms, traffic lights for all the lanes were set to same color. Left turn, right turn and straight pass through signalized intersection were tested. Left, right and middle lanes were used to ensure that the system is capable of navigating around multi-lane intersection. It was observed that in all the tests that the system successfully detected the traffic light and stopped as intended for red and yellow. The driving behavior for red and yellow light was similar to the behavior at stop-sign, except that the vehicle waits for the signal to turn green.

5.2.3 Key Conclusions

Following conclusions are drawn from the data analysis results and operator observations.

In absence of secondary obstacles, the ADS platform is capable of:

1. Coming to a complete stop before the stop bar for traffic lights and stop-signs.
2. Accelerating to speed limit from stop.
3. Passing without stopping through a green signal.

However, some drawbacks were noticed:

1. The traffic light detection system is sensitive to camera calibrations and is not reliable at longer distances.
2. The system starts steering at zero speed after the stop.
3. The system controller commands brake and throttle at the same time.
4. Vehicles turn signal behavior is not consistent.

5.3 Obstacle Detection

After completing tests to ensure driving safety of the system with no obstacles, the next step was to test the system's capability of detection objects around it. For the safety of the driver, the system under test, and the soft targets, tests were only conducted with stationary obstacles. The main objective of these tests is to validate capability of the system to avoid obstacle along its desired path or maneuver around obstacles that are not directly on the planned path.

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5.3.1 Test Matrix

The object detection and avoidance module includes a machine learning algorithm to detect objects in the point-cloud data from LiDAR, object localization, and control command to avoid obstacle. Accuracy and confidence of object detection algorithms depend on the type, size, and distance of the objects. Hence, the following different objects were considered – car, adult pedestrian, child pedestrian, bicyclist, motorcycle, and trailer. Localization of detected objects pertains to checking if the object is in the planned path and if evasive action is required. To validate localization capabilities, tests were conducted on straight and curved roads.

The first step was to only drive past a stationary obstacle and validate detection accuracy and detection distance. It was found that the system's detection range was limited due to the type of the LiDAR. Although, the system is intended to function at speeds up to 55mph, the limited object detection range of the LiDAR restricted testing to speeds up to 35mph.

The second step was to determine if the vehicle could avoid collision with the obstacle. In these tests, obstacles were placed on the planned path. Following variables were chosen as test parameters for the obstacle detection and avoidance testing:

1. Vehicle speed: Low(15-35mph) /High (35-55mph)
2. Object type: Car, adult pedestrian, child pedestrian, motorcycle, bicyclist, trailer
3. Road geometry: Straight, curved
4. Location of the obstacle with respect to the planned path: Left lane (L) , right lane (R), same lane (S)

The test matrix designed using above test parameters is give in Table 6 and Table 7.

Table 6: Straight road test matrix 1 for stationary obstacle avoidance validation

Test Parameters	Stationary Obstacles																				
POV	Softcar						Adult Pedestrian			Bicyclist			Motorcycle			Trailer			Child Pedestrian		
Speed	15-35			35-55			15-35			15-35			15-35			15-35			15-35		
POV Lane	L	R	S	L	R	S	L	R	S	L	R	S	L	R	S	L	R	S	L	R	S

Table 7: Curved road test matrix for stationary obstacle avoidance validation

Test Parameters	Stationary Obstacles											
Road Curvature	Left						Right					
POV	Softcar			Adult Pedestrian			Softcar			Adult Pedestrian		
Speed	15-35			15-35			15-35			15-35		
Van Lane	L	R	S	L	R	S	L	R	S	L	R	S

After testing on straight road, it was found that the object detection capabilities are the same for adult pedestrian, bicyclist and motorcyclist, hence only adult pedestrian was used for curved road testing. The system failed to detect child pedestrian, hence tests with child pedestrians were also not repeated on curved roads.

5.3.2 Results

Obstacle tracks are plotted in Figure 22. The different colors indicate different tests and only one out of 3 repeated tests are plotted as the repeated tests did not differ significantly. The obstacle locations are reported in global coordinate systems. These locations are then transferred into vehicle centric coordinate system using vehicle location and heading angle as reported by the localization module. Further, the obstacle detection distances at first detection are shown in Figure 23. Most importantly, the detection distance for child pedestrian and van/trailer (approx. 24m) are lower than other objects (approx. 50m).

Assuming 24m detection distance and 0.3g of deceleration rate, the maximum speed from which the vehicle can come to a stop and avoid hitting the obstacle would be 26.59 mph, as shown below.

$$v_0 = \sqrt{2 \times 0.3 \times 9.8 \times 24} = 11.89[m/s] \; = \; 26.59mph$$

In other words, the vehicle driving at approximately 26.59mph will not be able to detect child pedestrian early enough to be able to come to stop.

Similarly, for larger objects like cars and adult pedestrians, the detection distance is approximately 50m. Hence, assuming 0.3g of deceleration rate, the maximum speed from which a stopped obstacle could be avoided is 38.36 mph.

$$v_0 = \sqrt{2 \times 0.3 \times 9.8 \times 50} = 17.14[m/s] \; = \; 38.36mph$$

The system was able to place obstacles in correct lanes on the curved roads and passed or stopped for the obstacles as intended.

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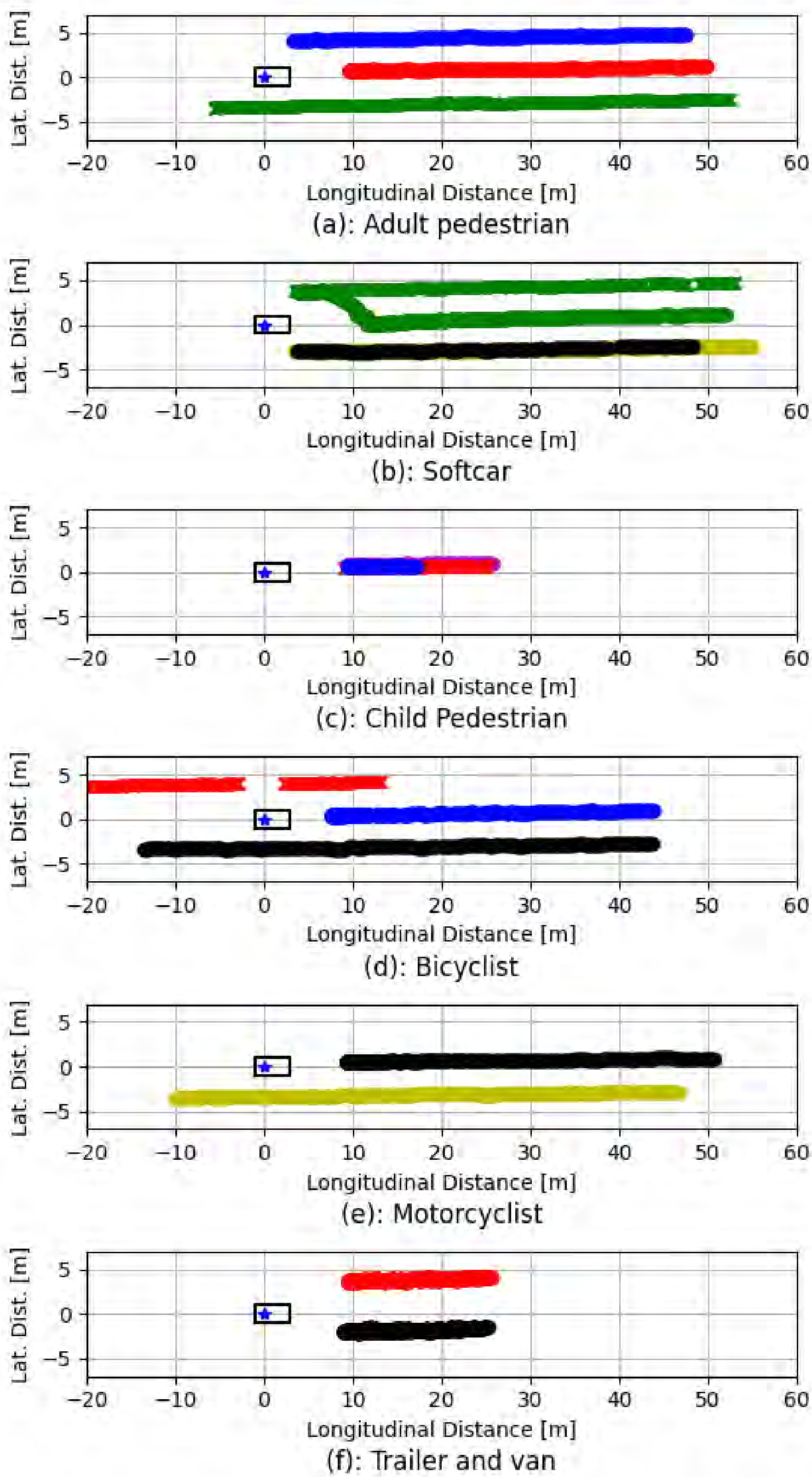

Figure 22: Tracks of the obstacle centers detected by the system plotted in the vehicle centric coordinate system.

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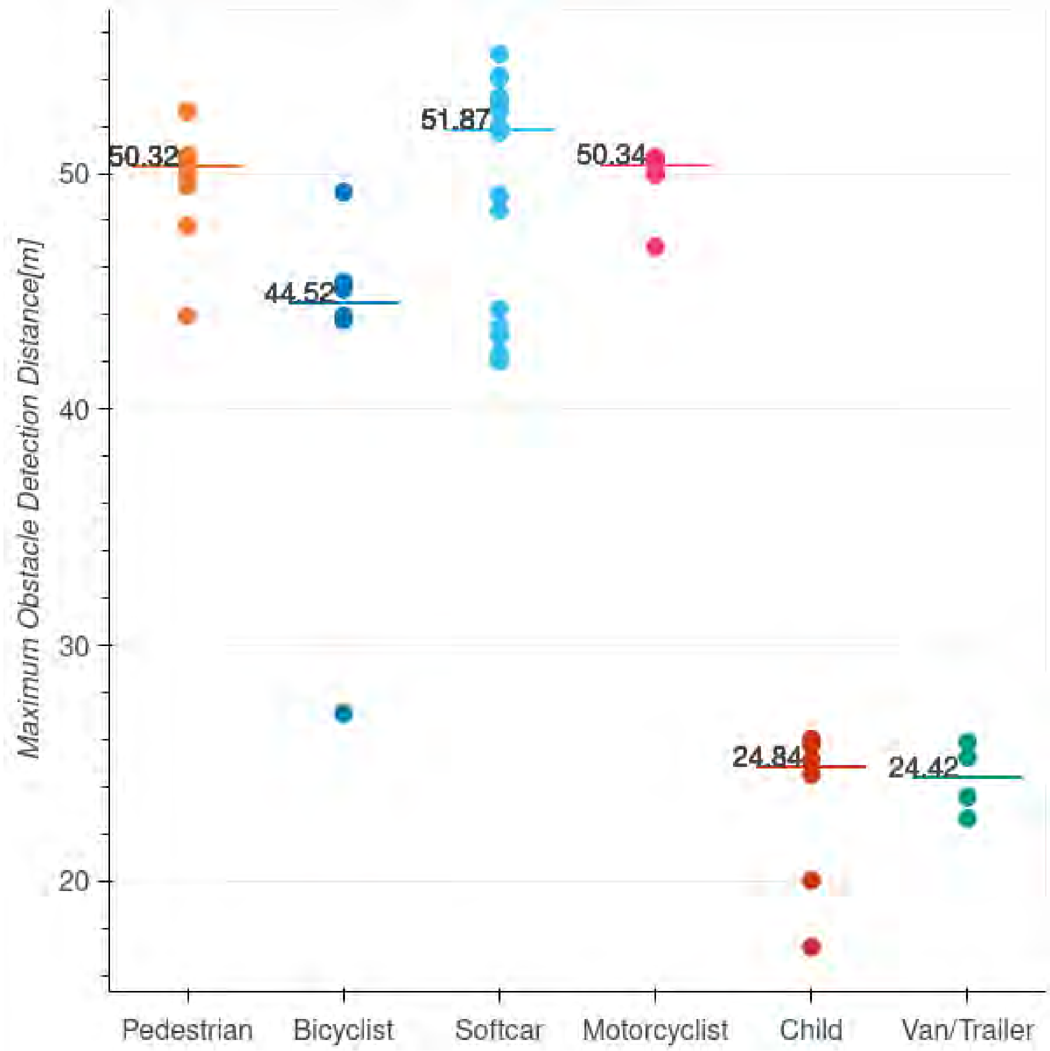

Figure 23: Maximum obstacle detection distances for all tests. The annotated horizontal lines indicate mean detection distance.

5.3.3 Key Conclusions

Following main conclusion are drawn from the data analysis results and operator observations.

In absence of secondary obstacles, the ADS platform is capable of:

1. Detecting and avoiding cars, adult pedestrians, adult cyclist, and motorcyclist at lower than approximately 35 mph speeds.
2. Localize detected objects correctly and place detections in correct lanes.

However, the system has some safety critical concerns.

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1. The system failed to detect small objects like child pedestrians and larger objects like van and trailer at a distance sufficient enough to be able to come to complete stop from more than 26 mph.

6 Testing Conclusions

The following section breaks down the executed tests into issues discovered and extrapolates that behavior to potential on road issues and ways to safely operationalize the system during deployment.

6.1 Software Bugs and Fault Diagnostics

During testing in numerous ADS categories there were unrelated software ‘bugs’ and other problems with insufficient fault diagnostics. The following is an example of a software bug:

- There were numerous occasions during CE testing where the ADS stack would disengage without warning to the driver. Generally, there was no underlying reason apparent in the software readout to explain why the ADS stack disengaged. One unverified reason behind these disengagements could be interference due to external radio and WiFi communication.

There were also numerous problems with system’s fault diagnostics. Fault diagnostics is important in mobility systems because they are the first step in determining the source of an error or failed subsystem in a vehicle and is typically followed by a remediation action(s). These actions might be as simple as turning on a malfunction indicator lamp (MIL, also referred to as a check engine light) or could result in the torque production of the vehicle being limited. Fault diagnostics is more complicated for an ADS because of the nature of automating the driving and largely falls outside of the scope of this document. However, additional information of fault diagnostics in ADS can be found in ISO 21448. The following is one example of a failure that should have been caught by fault diagnostics:

- The ADS was able to be engaged without the LIDAR sensor being turned on, meaning the vehicle was effectively driving blind without any object detection.

Furthermore, without sensor redundancy in critical areas, there is no way to effectively detect faults that may occur. For example:

- There is only a single GPS sensor with RTK corrections in the vehicle and the default software configuration of the vehicle employs only that single GPS with RTK corrections as a means of localization. This means that if the GPS or RTK corrections are incorrect, the ADS will not be able to localize itself to the correct portion of the lane.

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These examples for fault diagnostics demonstrate the limitation and immature nature of the software package.

6.2 Perception

During CE testing, it was noticed that the Apollo system was not able to avoid stopped obstacles when driving above 35 mph. This led to further investigation into the system's object detection capabilities. Tests with different target objects, distance, and speeds were conducted by TRC Inc. at TRC SMARTCenter. At the end of these tests, it was concluded that the Apollo system has object detection range of approximately 50 m for standard sized cars and adult pedestrians. The detection distance is ~25 m for large objects like truck trailers and small objects like child pedestrians. The Hexagon team and Iowa team have experienced similar object detection distances with identically configured systems. Assuming 50 m object detection distance, the vehicle will not be able to come to a complete stop from speeds above approximately 35 mph. Hence, the recommendation is to drive manually if a stopped or slow moving obstacle is present in the driving lane while driving at the speed above 35 mph.

6.3 Localization

Currently, the system is entirely dependent on GPS/RTK corrections for localization. Reliance on a single sensor for any safety critical operation presents its own safety risks. Beyond reliance on a single sensor, the localization system did experience isolated problems with localization. The isolated problems resulted in the ADS localizing itself to an inappropriate location or heading angle. TRC team has developed a dash-light to communicate GPS/RTK status to the driver, so that the driver can be ready to take over if RTK is lost.

6.4 Traffic Light Detection

The TRC Inc. team observed that Apollo traffic light detection system is not reliable. The uncertainty in the detection could be due to calibration of the camera, the detection algorithms, position/orientation of the vehicle, etc. During the initial system assessment and learning phase, the detection algorithm was calibrated multiple times, and it was concluded that the uncertainties could not be resolved. Hence, a dashboard indicator light was designed and implemented to show the traffic light color the Apollo is perceiving. This way if there is a discrepancy between the Apollo's perceived traffic light color and the actual traffic light color, the driver can disengage and drive manually.

6.5 Lane Keeping on Curved Roads

The TRC team experienced uncomfortable driving on curved sections. The system was able to keep the vehicle inside the lane line markings, but it did not slow down enough to ensure comfortable lateral acceleration and lateral errors. The driver and the operator indicated that it

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felt like the vehicle was going to leave the road and would have slowed down if manually driving. It is therefore advised to disengage on the curved road if the system does not slow down to a comfortable speed.

6.6 Lane Change in Presence of Principle Other Vehicle (POV) in Blind Spot

TRC Inc. ran tests where a platform with SoftCar was in the blind spot when the system's objective was to make a lane change. This scenario is shown in Figure 24. It was observed that the system went too close to the POV. This is possibly due to conflicting decisions between obstacle avoidance and planned route. In a very unlikely scenario where the POV stays in the adjacent lane while the system is attempting lane change, the vehicle may start drifting towards the POV. Hence, when the system attempts to make a lane change and there is another vehicle nearby in the adjacent lane, it is recommended to disengage and drive manually.

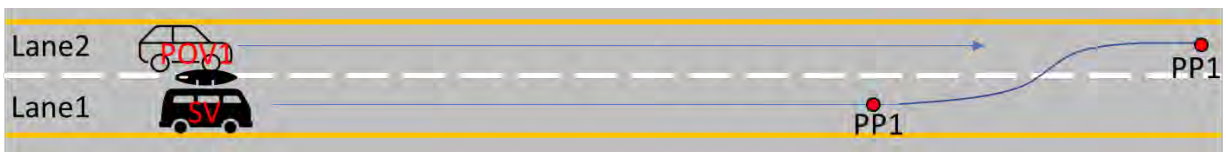

Figure 24: Lane change scenario with POV in blind spot

6.7 Sudden large steering torque when engaging at speed:

A CE test was conducted to assess the ability of the system to engage or re-engage into autonomous mode when manually driving at higher speeds. In this test, a routing request requiring lane change was sent. The vehicle was driven manually for some distance in the same lane and then, while driving, the system was engaged into autonomous mode. It was observed that the system replanned to route and made a sudden lane change with unacceptable steering rate. To avoid this situation, it is recommended not to engage the vehicle in autonomous mode while driving at higher speed when the planned route has an upcoming lane change on the same road segment.

6.8 Summary of Conclusions

Table 8: Summary of safety critical issues and plan to operationalize for public road deployment.

Issue	ODD	Solution (Disengagement conditions)
Object detection distance is ~50m	Van Speed: >35mph Other object: Slow/stopped in the same lane	When the vehicle fails to slow down at a comfortable rate, disengage or drive manually.
High steering rate when engaging at high speed	Van speed: >5mph Event: Engage at speed when there is lateral error	Do not re-engage when driving at speed and when the vehicle is not at the (approximate) center of the desired lane

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Traffic light detection uncertainty	Location: Approaching or stopped at signalized Intersection	Check traffic light indicator to ensure the Apollo stack perception is detecting correct traffic signal. In presence of discrepancy, drive manually.
Detection distance is ~25m for small objects	Van speed:>25mph Other object: Slow or stopped in the same lane	If the vehicle fails to start slowing down in presence of obstacles, disengage and do not wait for the vehicle to react.
Fails to detect large objects (trucks and busses)	Other object: Bus, truck-trailer	Keep safe distance from large objects. If vehicle is unable to keep safe distance, disengage and drive manually
In-accurate lane keeping on curved roads	Van speed:>25mph Road: Curved	If vehicle fails to slow down for curved roads, or fails to stay in the lane, take over and drive manually
Does not allow other vehicle to pass when immediate Lane change is required	Other object in blind spot Immediate Lane change required	If vehicle starts drifting towards adjacent lane when there is vehicle in blind spot, disengage and drive manually. Make a lane change safely and then re-engage.
Apollo trying to do a hard stop on the road.	Van Speed > road speed limit or the max speed limit set for the road in the maps.	Do not engage Apollo when the Van speed is higher than the road speed limit; bring the van closer to the road speed limit and engage Apollo.

The recommended solutions are purposefully kept subjective to driver's perception of safety as objective measurements of safety metric are not feasible. The recommendation is to disengage when driver feels unsafe.

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Appendix A – Testing Equipment and Facility

A.1 Testing Equipment

OXTS RT3000 V2 and V3:

- IMU and GPS unit
- Measures position, orientation and dynamics of a vehicle in real-time
- Position accuracy: 2 cm
- Slip angle accuracy: 0.15°
- 100 Hz data output rate

OXTS RT-Range:

- V2V, V2X and Vehicle-to-lane measurements in real-time
- Up to 1km range between hunter and targets
- Can measure up to 4 moving targets simultaneously

Freewave Differential Correction:

- Use local base station's signal to improve GPS' accuracy

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Brake and Throttle Robot:

- 2 SEA units and 2 ABD units
- Ability to maintain a constant speed or acceleration within tolerance
- Can perform correct amount of deceleration


Steering Robot:

- 1 SEA unit and 1 ABD unit
- Path following ability
- Lane centering driving ability


ABD Guided Soft Target (GST):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 100 km/h (27.8 m/s)
- Forward acceleration up to 0.2g and deceleration up to 0.8g
- Synchronization with the test vehicle with path following ability
- Has heavy duty ramps for Semi testing

DSD Ultraflat Overrulable Robot (UFO):

- Self-propelled platform carrying Soft Car 360
- Capable of moving at maximum speed of 65 mph (29.1 m/s)
- Forward acceleration up to 0.3g and deceleration up to 0.6g
- Synchronization with the test vehicle with path following ability
- Removable side ramps and batteries

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DSD Pedestrian Arm:

- DSD UFO's extension kit to pull pedestrians
- Attaches to the UFO and detaches on impact to the pedestrian

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A.2 Testing Targets

NHTSA Strikeable Surrogate Vehicle (SSV):

- Allows for testing of constant speed, accelerating and decelerating lead vehicle
- Representative of small hatchback from rear only

EuroNCAP Soft Car 360:

- Representative of a small hatchback from all angles
- Can take impacts and be reassembled in 10-15 minutes

Pedestrians: Static Adult and Static Child

- 4activeSystmes static dummies that replicate properties of stationary pedestrians in size, shape and radar cross section
- Can take impacts up to 60 km/h (16.7 m/s)

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Pedestrian: Bicyclist

- 4activeSystmes dummy that replicate properties of a bicyclist in size, shape and radar cross section
- Can take impacts up to 60 km/h (16.7 m/s)

Pedestrian: Motorist

- 4activeSystmes dummy that replicate properties of a motorist in size, shape and radar cross section
- Can take impacts

Sign Inventory

- Speed signs
- Traffic signs

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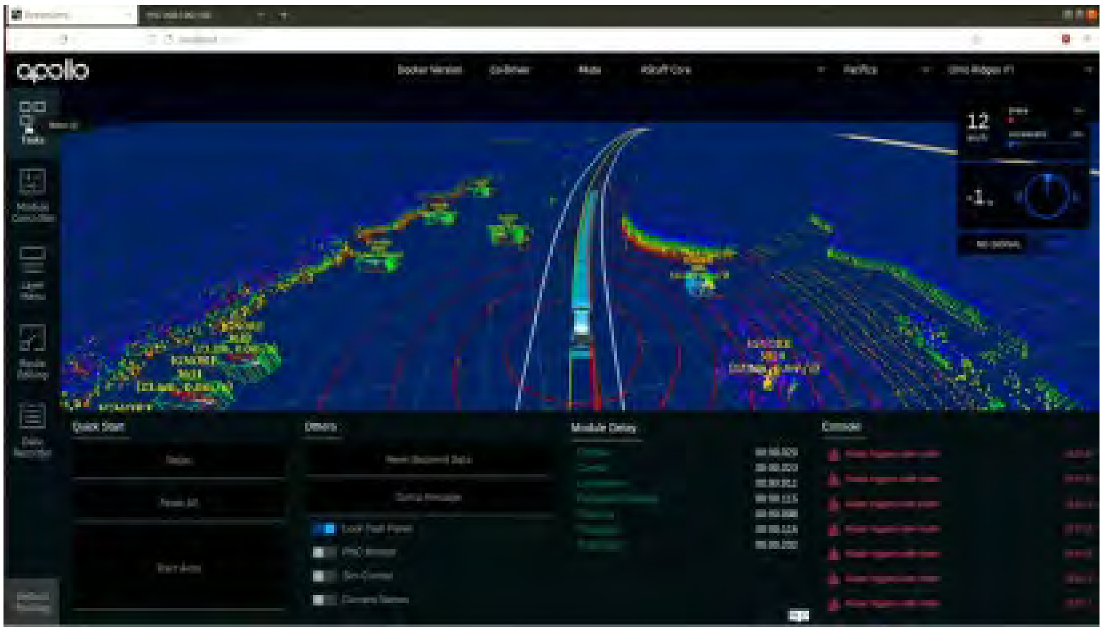
Appendix B6
OU Controlled Environment Testing Report

Controlled Environment Test Plan for Apollo



Prepared by:
Jay Wilhelm, Ph.D.

Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

July 2023

Interim Report

Ohio Research Institute for
Transportation and the Environment

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Controlled Environment Test Plan for Apollo

Prepared by

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Prepared in cooperation with the
Ohio Department of Transportation
and the
U.S. Department of Transportation, Federal Highway Administration

Interim Report
July 2023

Credits and Acknowledgments

Prepared in cooperation with the Ohio Department of Transportation
and the U.S. Department of Transportation, Federal Highway Administration

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Appendices

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Tables

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1 Introduction

This report documents the verification of Apollo software to operate the IDEAS Automated Driving Systems (ADS) vehicle in fully automatic mode in a Controlled Environment (CE). It includes a brief description of the IDEAS vehicle, the test route, and the test plan/procedure. The ADS vehicle generally followed the test route successfully, though some issues are noted in the findings.

1.1 Objectives

The objective of the portion of the research project documented here is to verify the operation of the Apollo software in guiding the IDEAS vehicle through a controlled environment consisting of a test loop on a private road on two trips. Successful operation includes collection of a complete set of data from LiDAR, GPS, and camera for both trips along with complete screen captures of Dreamview during manual and autonomous driving. The same trips were simulated, and the recordings compared to the real-life trips to find any problems or disengagements. If a simulated trip had more than three disengagements, the problems were corrected, and the simulated route travelled again. Additional objectives included ensuring the system could identify stop signs and streetlights and ensuring the system could identify other vehicles and pedestrians.

2 Research Approach

The research approach can be broken down into components which will be described in the following sections. The first is the test vehicle, which is a specially modified automobile outfitted with an array of sensors. There are several software elements that handle various aspects of vehicle operation, including gathering sensor data, processing the sensor readings in real time in combination with route data, and controlling the vehicle. The second is the test route, which is mapped using sensors and software to create input for the vehicle. Also discussed are the safety and operating procedures.

2.1 Description of Test Vehicle

The IDEAS vehicle is a Chrysler Pacifica van equipped with Drive-By-Wire (DBW) capabilities by New Eagle [2023], shown in Figure 1, and outfitted for Ohio University by AutonomouStuff. Details on the drive-by-wire setup are in the product sheet in Appendix A and at the AutonomouStuff web site [2023]; the vehicle includes capability for electronic control of speed, throttle, brake, steering, and turn signals, all operating at 50 Hz, plus gear selection at 20 Hz, and high beam control, all of which could be operated via the Robot Operating System (ROS). The vehicle was then outfitted by Hexagon/AutonomouStuff with sensors, including Light Detection and Ranging (LiDAR), global positioning system (GPS), and an array of cameras. LiDAR point cloud data were gathered with the vehicle's included roof-mounted Velodyne VLP-32C, shown in Figure 2 (right). Velodyne's VLP-32C has 32 channels producing 300,000 points per second with a vertical field of view from -45° to +15°, providing a high output data stream. Image data were captured with forward-facing Allied Vision Mako G-319C Cameras, shown in Figure 2 (left), equipped with 16 mm and 12 mm lenses producing 2064×1544 pixel resolution images at 37 Hz and Leopard Imaging USB30-AR023ZWDRB cameras equipped with 6 and 25 mm lenses producing 1920×1080 pixel resolution images at 30 Hz. GPS data were recorded by the van's PwrPak7D-E2 GNSS and INS enclosure manufactured by Novatel equipped with two GNSS-502 antennas manufactured by NavtechGPS.

Figure 1. View of the test vehicle, a 2021 Chrysler Pacifica, Ohio State Vehicle License Plate No. 29-596

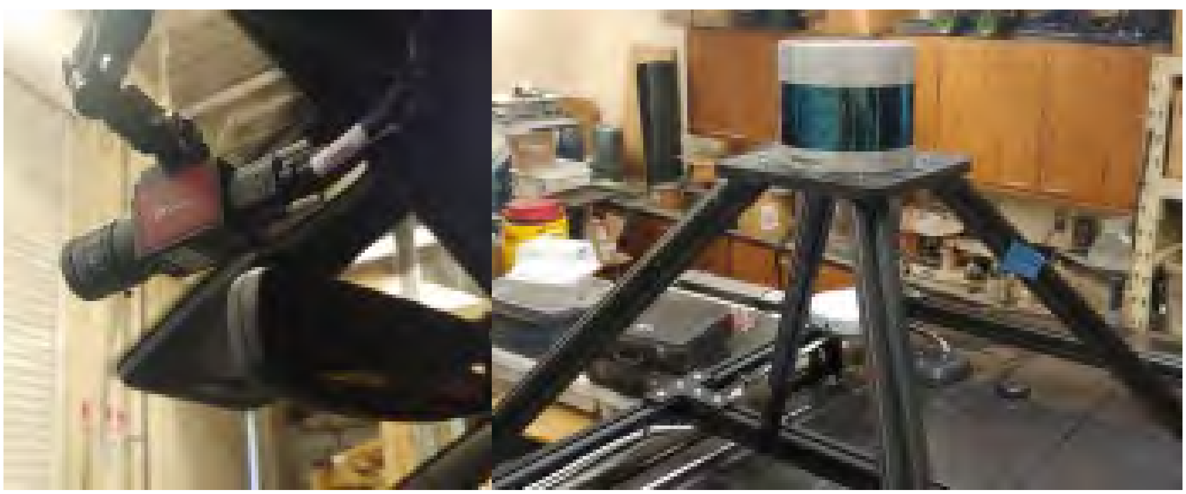

Figure 2. Left: Allied Vision Mako G-319C Camera, Right: Velodyne VLP-32C LiDAR.

Several software elements were used to record data and operate the vehicle. The software that controls the vehicle is called Apollo [2023]. Dreamview allows the researchers to see the environment as the autonomous vehicle sees it in Apollo. A program called RViz works with the ROS to visualize the data sent by the sensors. It is used to confirm the operation of the sensors as an independent check of what is seen on Dreamview. Figure 3 shows RViz being used to confirm sensor configuration.

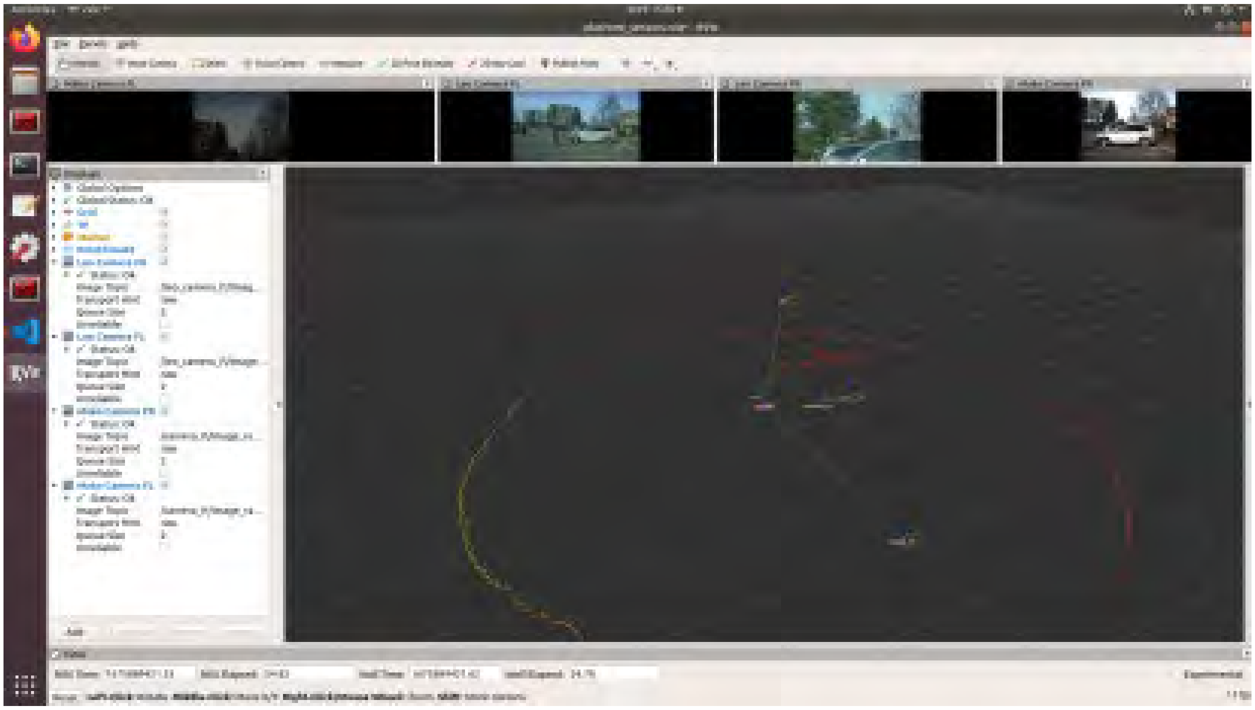

Figure 3. RViz is used to confirm correct sensor configuration.

2.2 Test Route

For this testing, a good test route would be a low-traffic low-speed environment with a limited length. A good location was the 0.5 mi (0.8 km) loop on Ridges Circle and East Circle Drive on the Ohio University Athens Campus on The Ridges, the grounds of the former Athens Mental Health Center and currently the location of the Kennedy Museum of Art. An aerial view of the location is given in Figure 4, with the test route loop outlined in Figure 5. Mandli was contracted to create high-resolution maps of the Ridges Loop, shown in Figure 6, as well as all other routes in this project. These maps were then used as inputs for the Apollo program. Test routes could either be clockwise on the inside lane or counterclockwise on the outside lane.

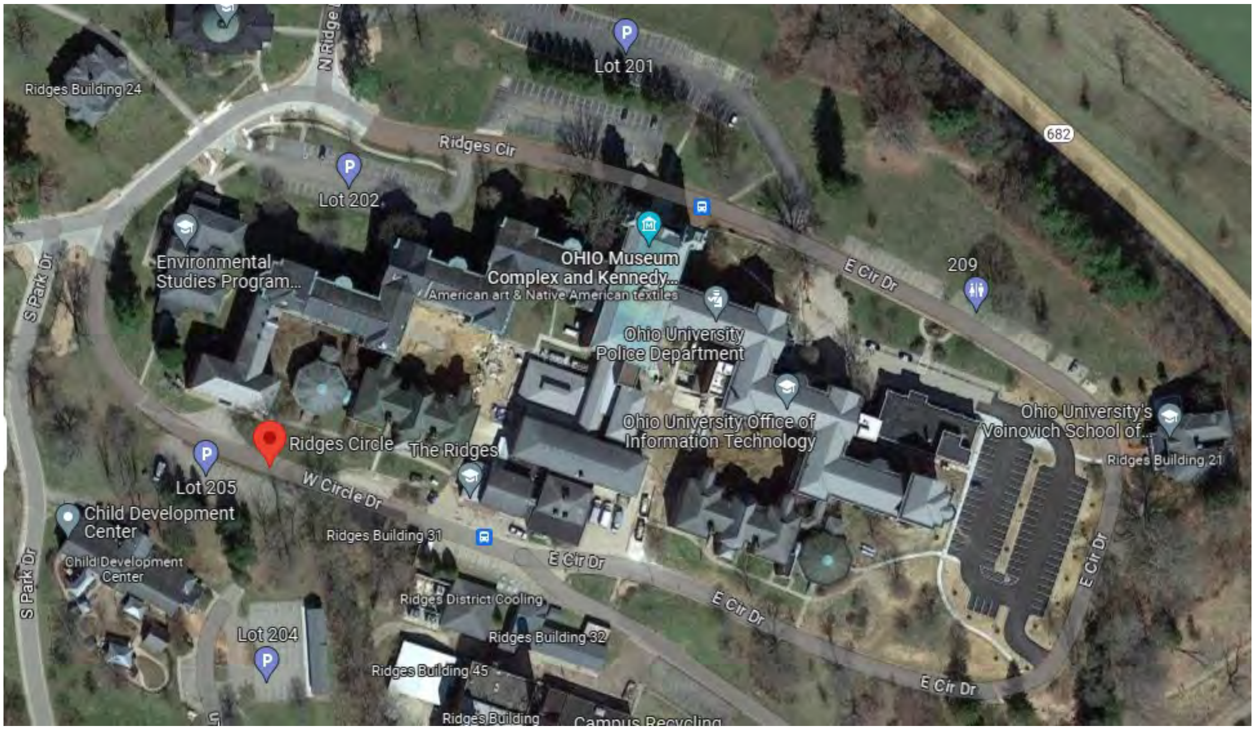

Figure 4. Aerial view of The Ridges on the Ohio University Athens Campus, showing Ridges Circle and E. Circle Drive [from Google Maps].

Figure 5. Aerial view of the Ridges with Ridges Circle/E. Circle Drive test route drawn in violet.

Figure 6. High definition map of the Ridges Loop provided by Mandli.

2.3 Controlled Environment Test

The IDEAS Automated Road Vehicle was tested within a controlled environment to verify the operation of the Apollo software to control the IDEAS vehicle in fully automatic mode on the test loop. Standard operating procedures (SOP) were followed according to the 01112022 version. Additional troubleshooting assistance was available through the DriveOhio ADS Project Passenger Vehicle Safety Management Plan (SMP) – version 02/25/2022 Table 3.1.

Pre-driving safety checks followed a checklist given in Appendix B, which began following the SOP for vehicle setup from shore through the start-up sequence. The operation of all the sensor systems (LiDAR, cameras, GPS, and RADAR) was verified in RViz and Dreamview. The GPS check included running a script from AutonomouStuff to verify reception of RTK solutions. However, after the tests, it was found that Novatel box was in RTK Single mode, indicating that the Continuously Operating Reference Station (CORS) correction factor was not in use. The drive-by-wire (DBW) system operation was verified using the Logitech controller system and checking the manual control of braking, steering, and throttle systems. It should be noted that AutonomouStuff stated that the use of the Logitech controller to test the Drive-By-Wire capabilities was inadvisable unless the Drive-By-Wire system was problematic during normal operation, as controlling the vehicle using the controller was difficult. The route maps were loaded by the Apollo system. The designated Safety Driver was Dr. Wilhelm, and a Secondary Safety Driver was assigned to the front passenger seat. The operator was instructed to inform the Safety Driver of traffic light detection status and any failures in the autonomous driving system.

After the safety check was completed, the CE test plan was followed. These steps began with manually (non-autonomously) driving the test loop twice at a controlled speed no more than 20 mph (32 km/h) while recording all sensor data collected at 100 Hz into a .bag file along with screen captures of Dreamview. The manual drive data are plotted in Figure 7 and were used to create the route map in Figure 8. The captured data were then played back in the Apollo simulation mode.

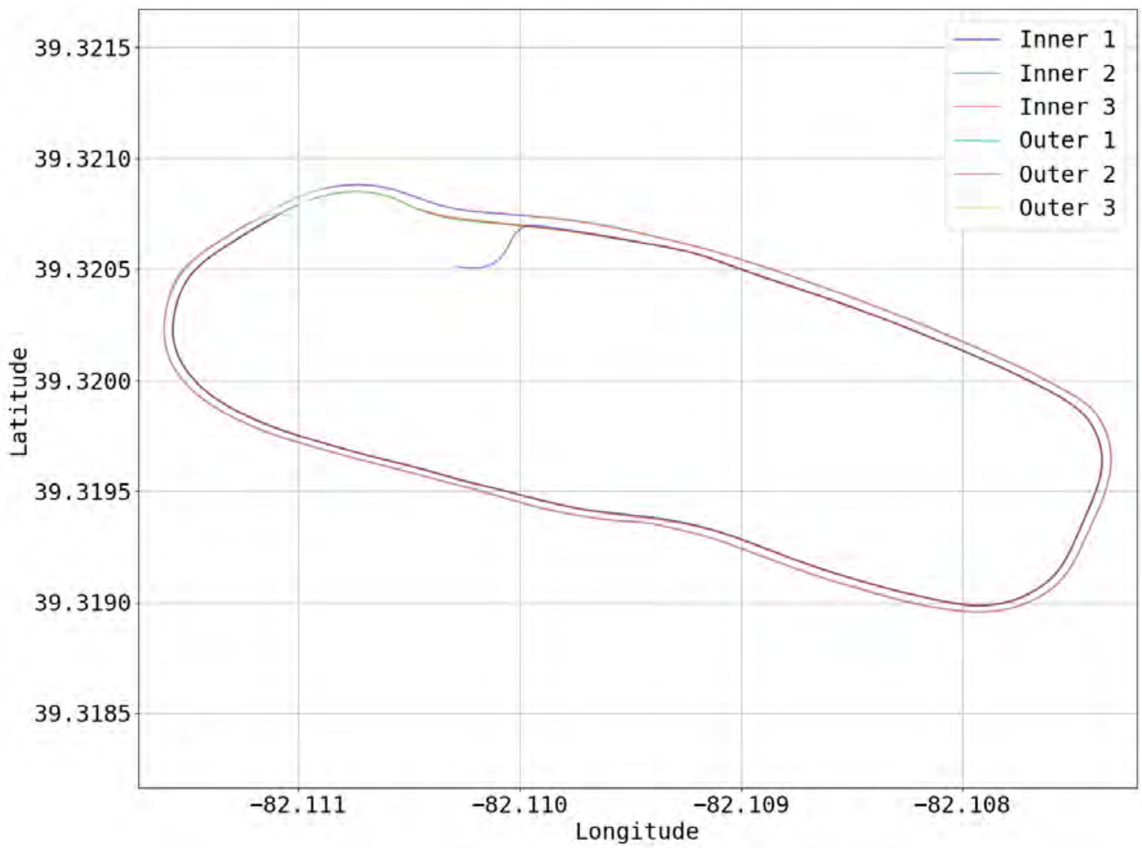

Figure 7. Ridges inner and outer loop manual driving data.

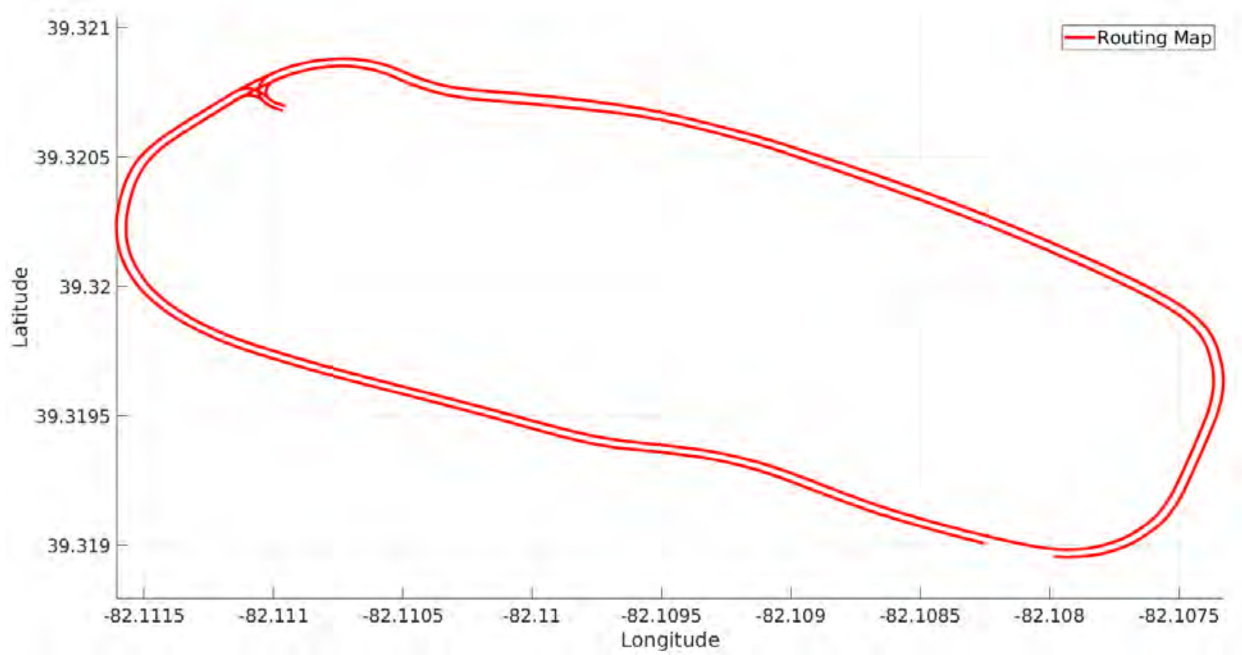

Figure 8. Routing map

The next step in the process was to play back the manually driven loops in an Apollo simulation to identify any problems ore disengagements, which would then be corrected. The software would be updated and the maps redrawn iteratively as needed to handle these disengagements or other problems until a functioning combination was identified. Figure 9 shows a Dreamview snapshot of Ridges Outer Loop simulation using Sim Control. No problems or disengagements were noted. The simulated localization for inner and outer ridges loop was created using the routing map in Figure 10.

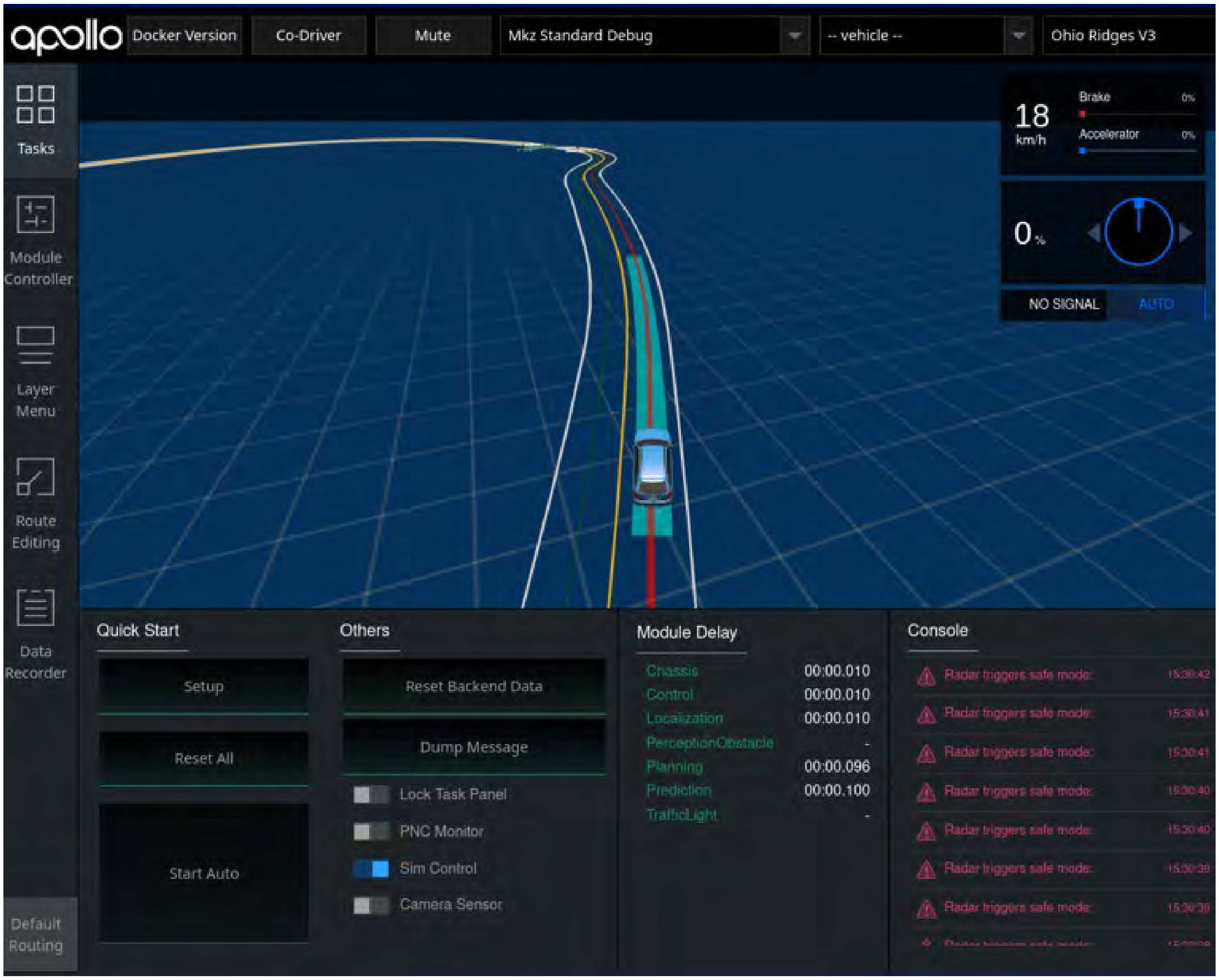

Figure 9. Ridges outer loop simulated driving Dreamview snapshot

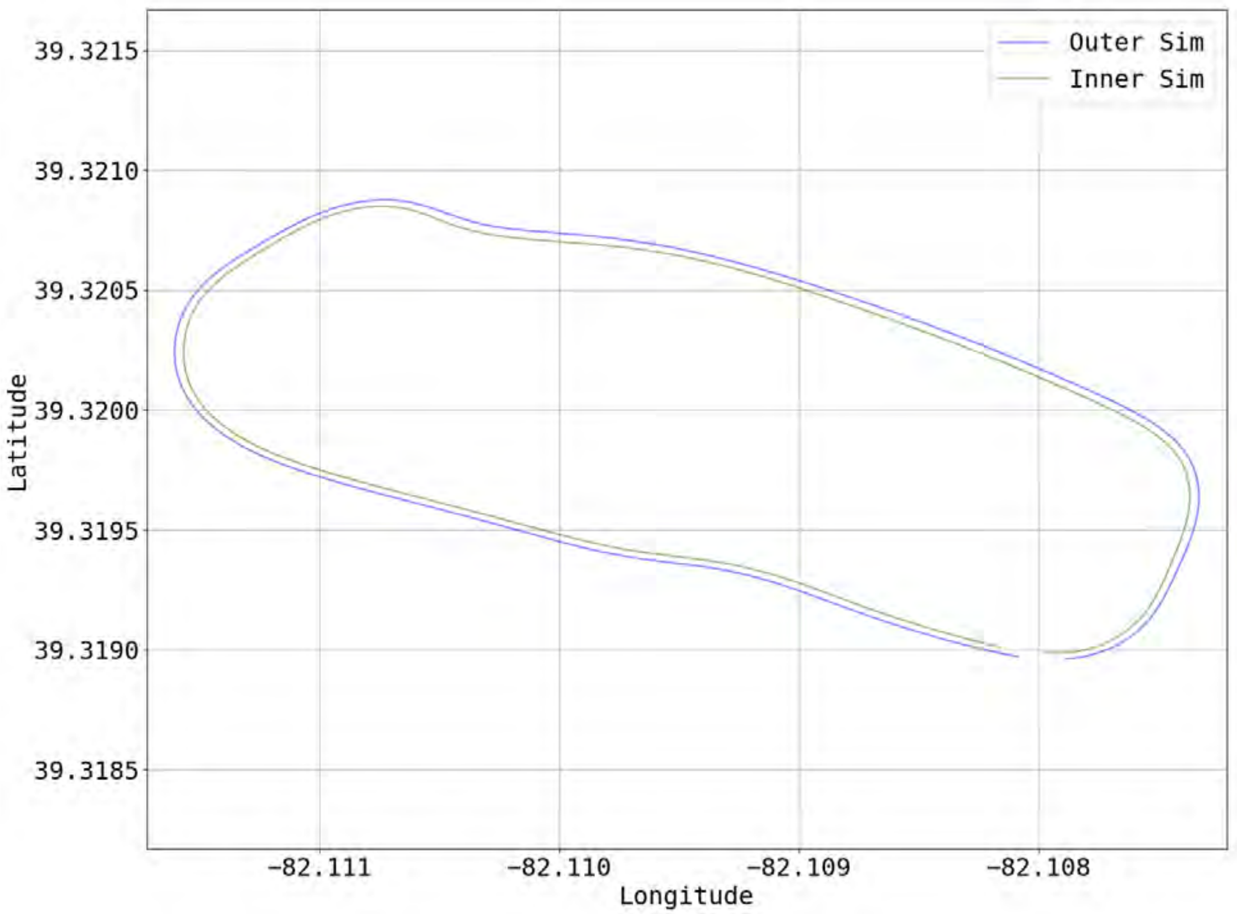

Figure 10. Simulated localization for inner and outer loop of Ridges

At this point the data were locked and then used to autonomously control the vehicle as it drove around the test loop at a maximum speed of 20 mph (32 km/h). The autonomous driving trajectories are shown in Figure 11.

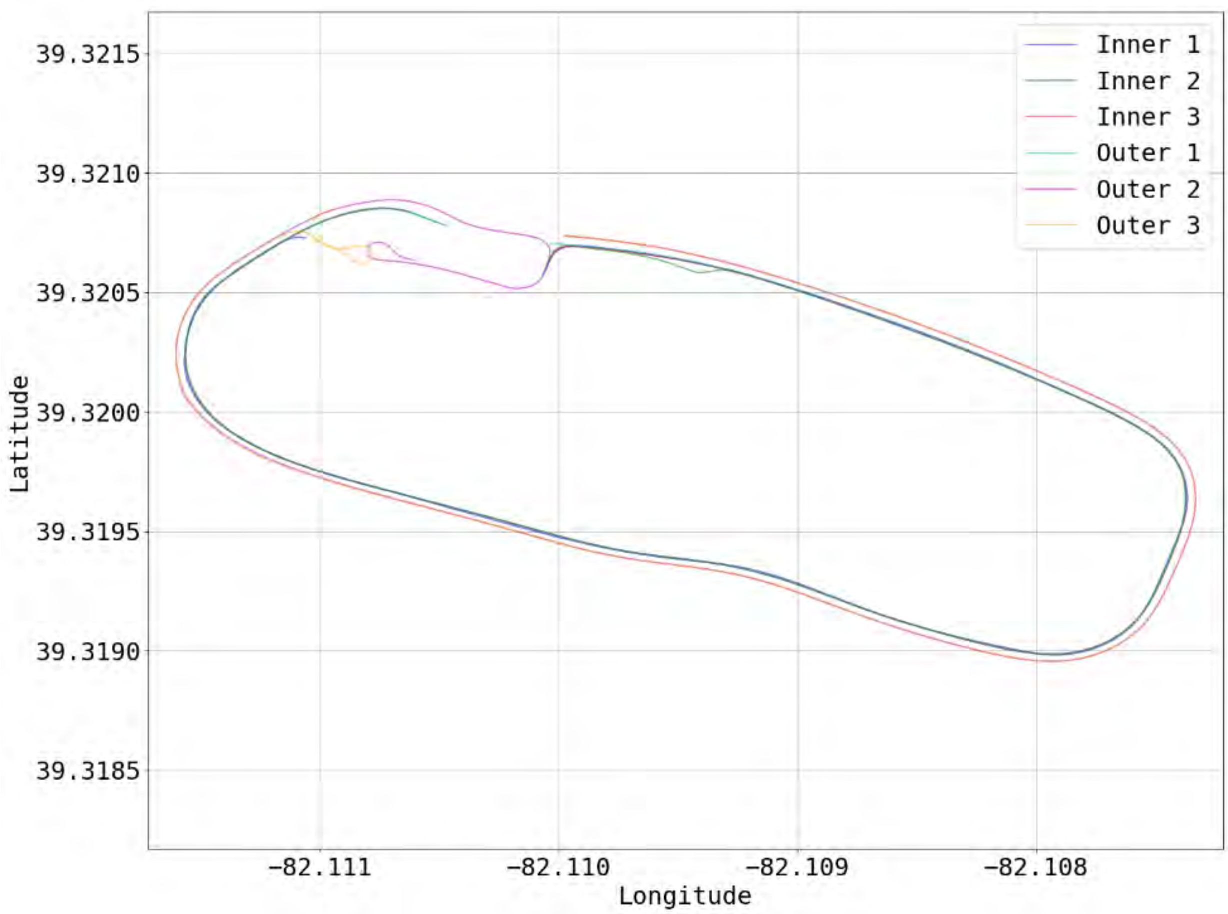

Figure 11. Ridges inner and outer loop autonomous driving.

Another objective of this project was to verify the Apollo system could detect and react to other vehicles and pedestrians, which appear in Dreamview as shown in Figure 12. Figure 13 and Figure 14 show how vehicles are detected by LiDAR and shown with bounding boxes in Dreamview. Figure 15 shows a Dreamview image of LiDAR detecting a pedestrian approaching the road and the system preparing to stop the vehicle.

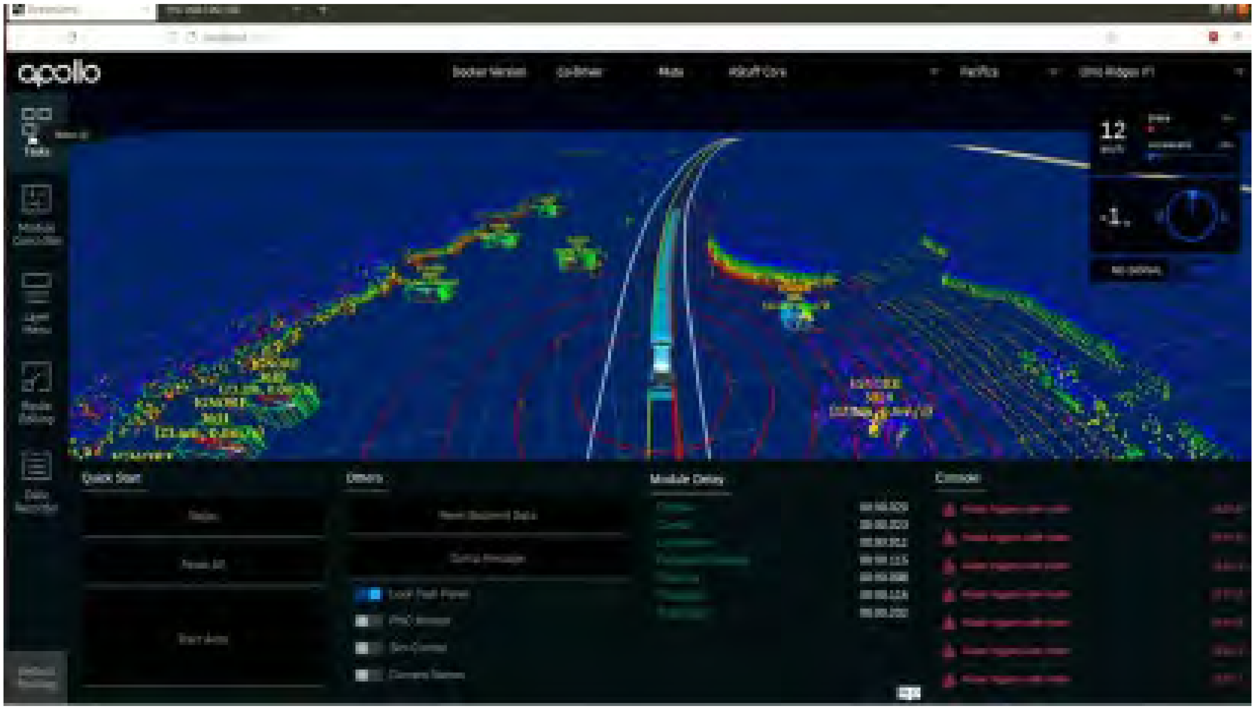

Figure 12. Dreamview showing the van displaying a trajectory.

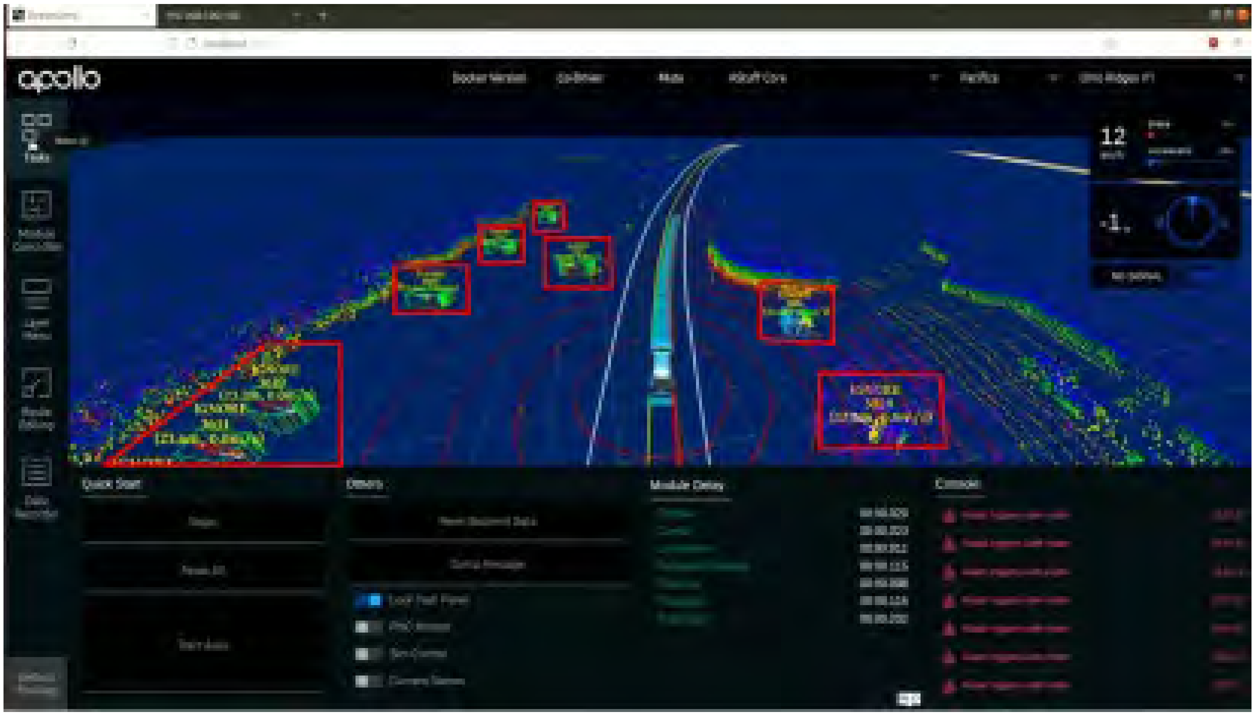

Figure 13. Dreamview display showing the van trajectory and detection of other vehicles and pedestrians in outlined shapes.

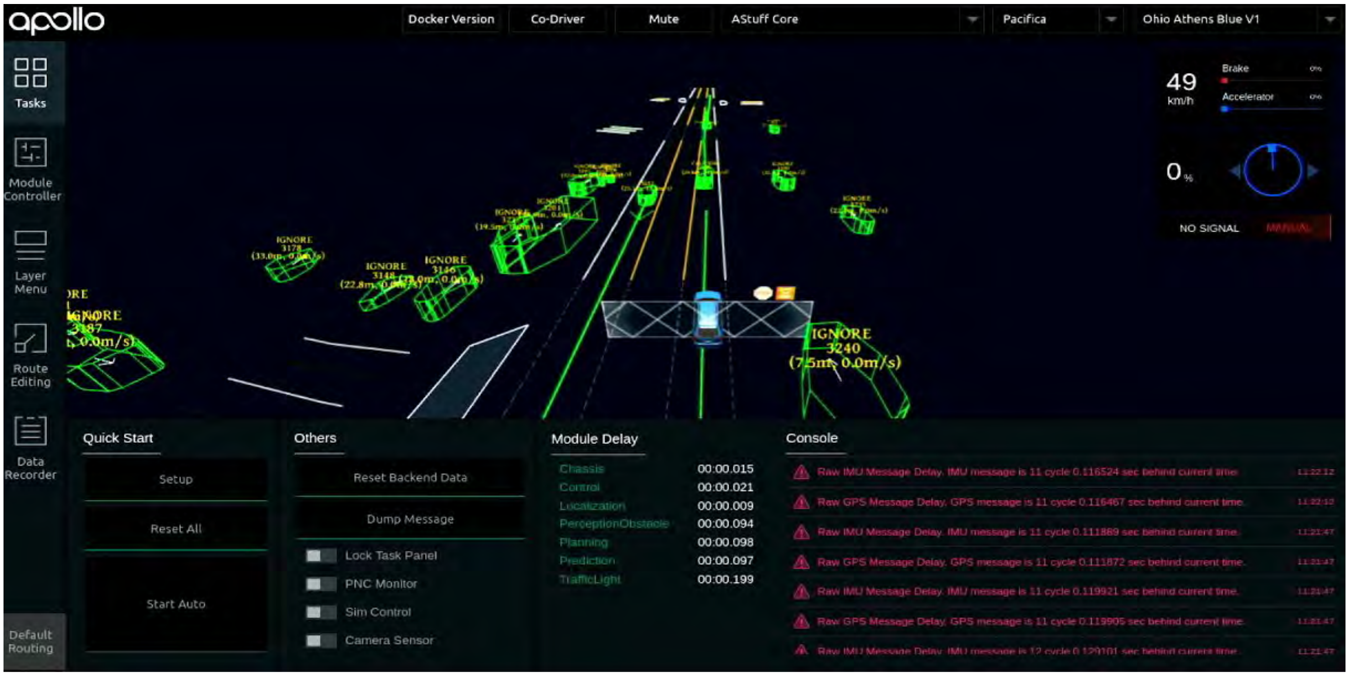

Figure 14. Vehicles are detected with LiDAR and shown in Dreamview as bounding boxes with a predicted trajectory

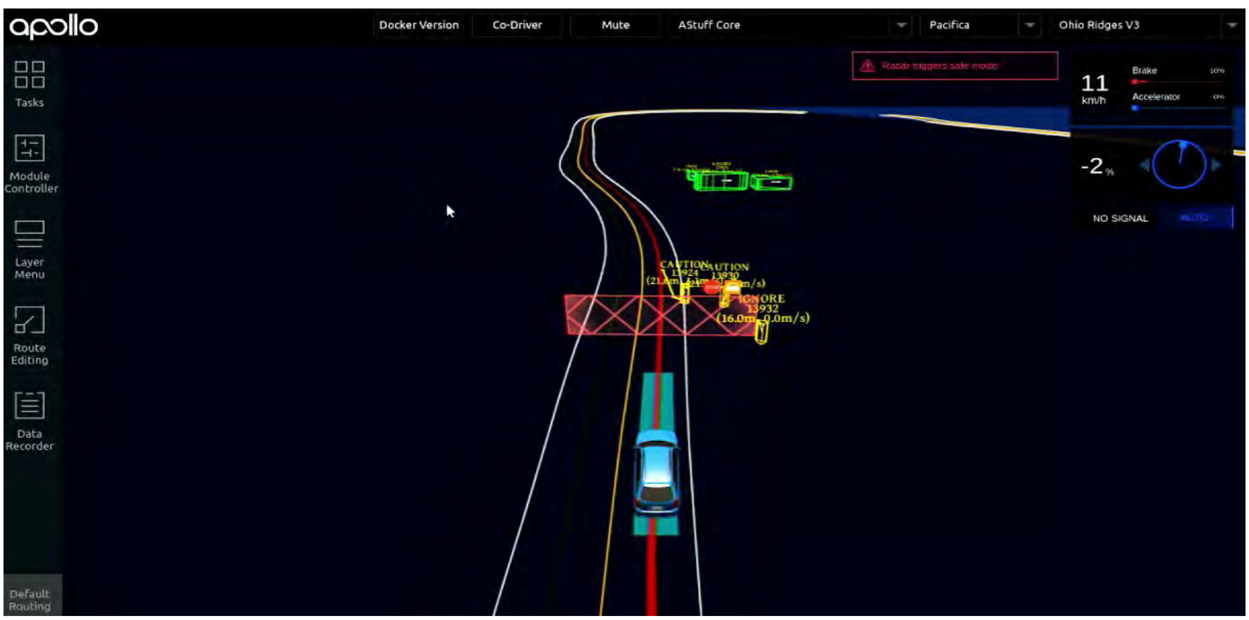

Figure 15. Pedestrians are detected using LiDAR and the vehicle plans a stop due to predicted pedestrian trajectory intercepting vehicle's trajectory

The test loop did not include any stop signs or stop lights. The vehicle was driven manually by some stop signs and stop lights with the sensors on and the data being collected to see how the system reacted. Figure 16 shows a Dreamview capture of a stop sign. Figure 17 and Figure 18 show how the vehicle system detects a stop light (in this case on SR 682 at the intersection with Union Street (SR 56) near the ODOT Athens County Garage) at far distance (green) and short distance (red), respectively.

Figure 16. Stop sign seen in Dreamview

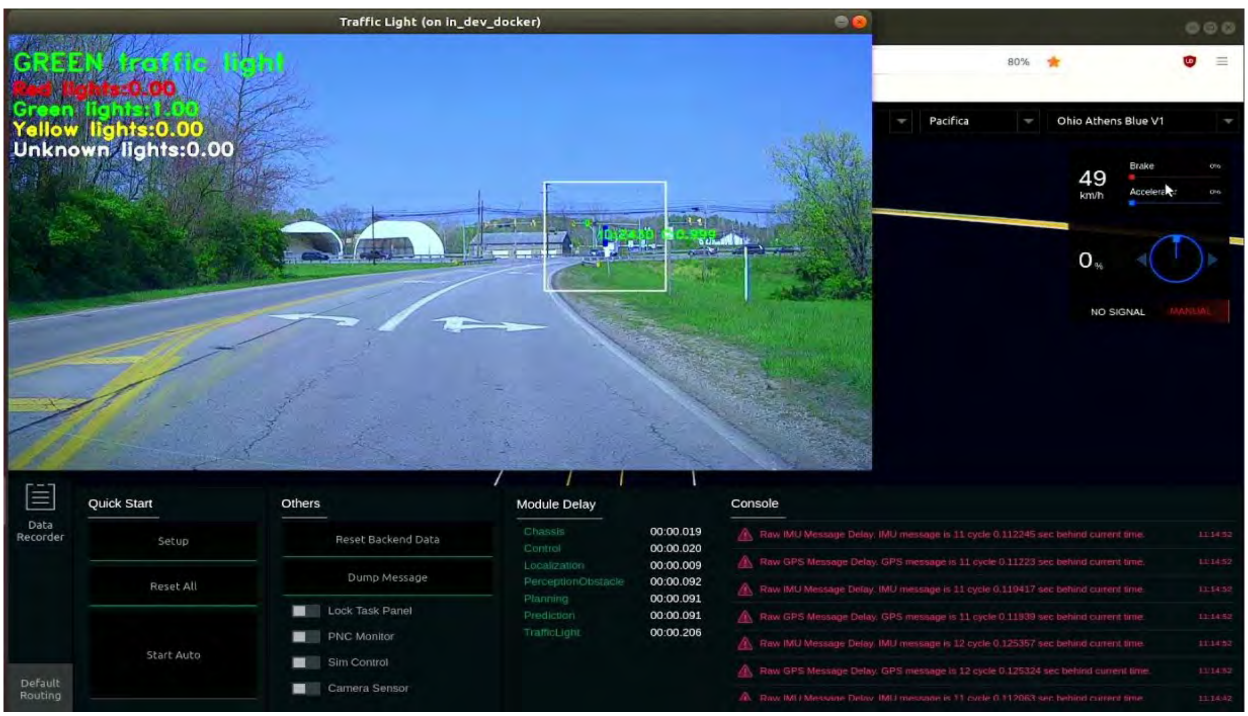

Figure 17. Long-range traffic light detection in Dreamview with overlay of camera view

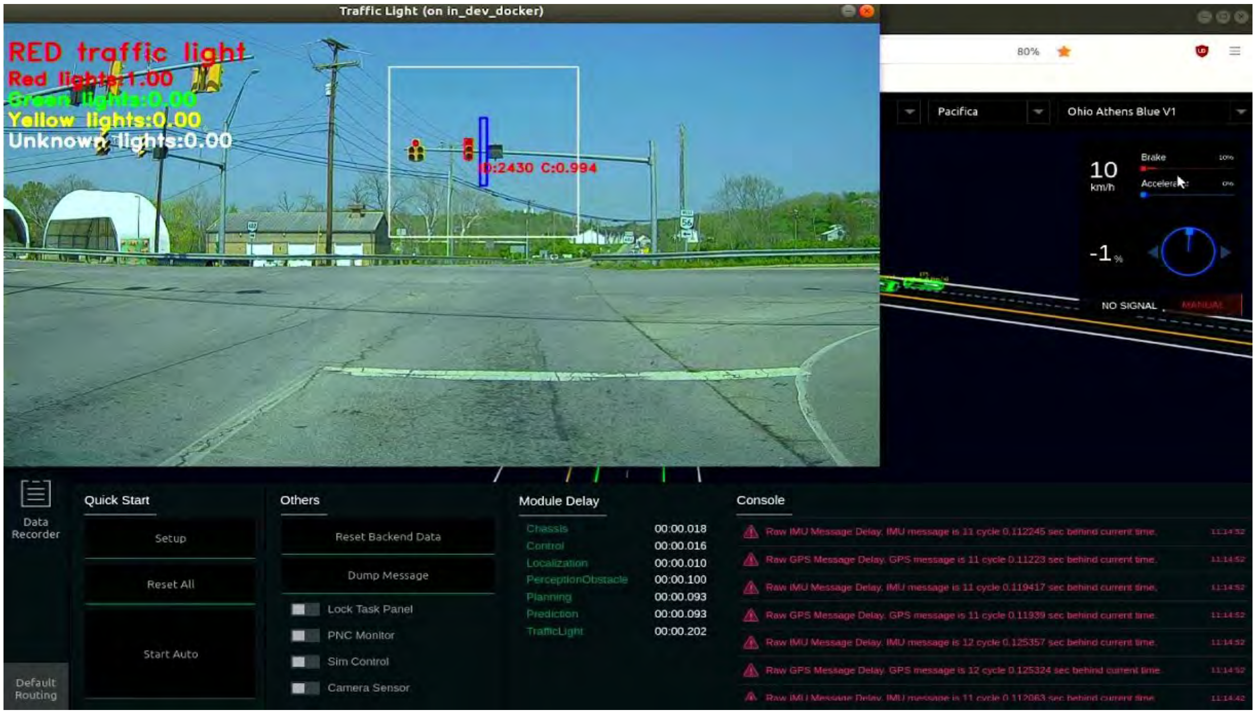

Figure 18. Short range traffic light detection in Dreamview with overlay of camera view

3 Findings

- Vehicle SOPs were followed to ensure safe operation.
- Test notes:
    - The van was manually driven along the entire Ridges Loop route to verify functionality of the map during physical testing.
    - Two autonomous runs were completed.
- GPS data were recorded using standard *cyber_recorder* functionality. Apollo provided Python scripts were used to extract GPS data from the */gnss/best_pose* channel
- Dreamview footage was captured using Open Broadcasting Studio (OBS), as in Figure 19.
- Due to map inaccuracies, such as shown in Figure 20, the van travelled left of center at one point during a test during autonomous driving conditions.
- RViz was used to confirm that all cameras, LiDAR, and RADAR were functioning properly (Figure 3).
- Dreamview simulation was used to verify Ridges Loop high definition map functionality
    - No disengagements or other problems arose during testing.
- Additional Concerns:
    - There were no stop signs or streetlights in the Ridges loop.
    - Apollo demonstrated the ability to detect both vehicles and pedestrians, these are outlined in Figure 13.
        - Apollo did not detect buildings
- During the second autonomous run, it was noted the van was not receiving Ohio Department of Transportation (ODOT) provided Continuously Operating Reference Station (CORS) data correctly, increasing GPS inaccuracy over time.
- Proper integration of the CORS correction factor into the GNSS solution is required for future testing.
- Further testing was postponed until the resolution of the issue, therefore data was only gathered when the van was going clockwise around the loop.
- Under autonomous driving conditions the van detected an incoming bus which it determined was in the van's lane, causing the van to stop to avoid impact.
- Upon successful diagnosis and correction of problems indicated above, additional autonomous driving will be completed on the controlled environment test route.
- Upon verification of overall autonomous driving performance, testing may be expanded to the other approved routes, designated red, green, and blue.
- The vehicle is limited to a maximum speed of 55 MPH.
- Oncoming vehicles may not be detected until within 25m if traveling above 35 MPH.

Figure 19. GPS Coordinates of the van drive laid over the Mandli map with the number of received satellite signals.

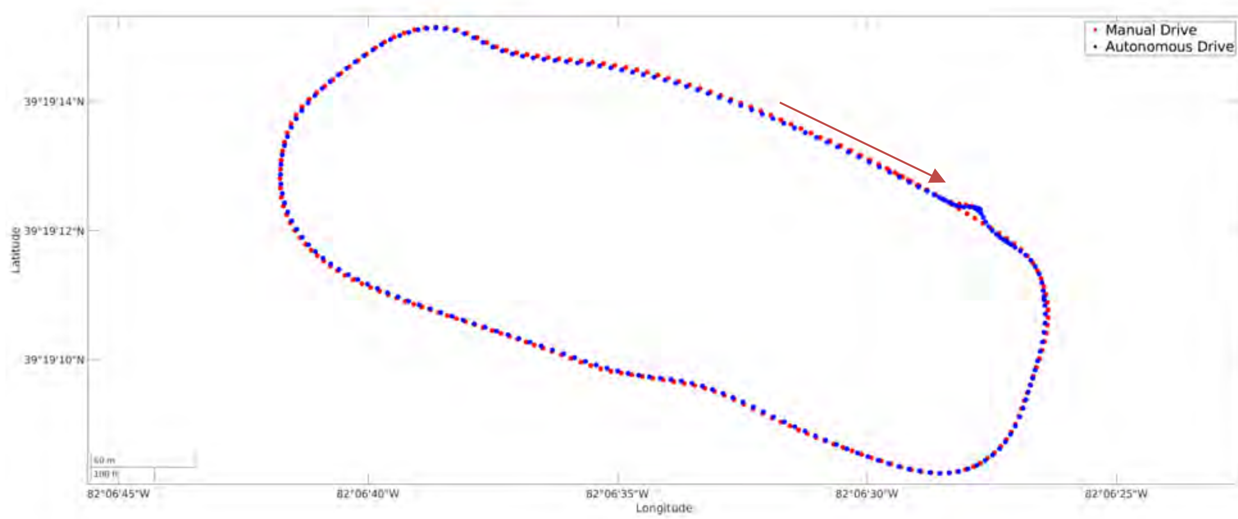

Figure 20. Manual drive versus the Autonomous Drive. The red arrow indicates the clockwise direction of travel of the vehicle. The slight offset in blue is where the vehicle veered left of center, indicating the map requires additional tuning.

4 Conclusions

Apollo has been tested given an initial plan and findings during testing to validate operation and define any decencies for the expected ADS project needs.

5 References

Apollo, [2023], “Open Platform” website, https://developer.apollo.auto/, accessed July 7, 2023.

AutonomouStuff, 2023, “Chrysler Pacifica”, https://autonomoustuff.com/platform/chrysler-pacifica, accessed July 7, 2023.

New Eagle [2023], “Platforms for Controlling Autonomous Vehicles” website: https://neweagle.net/autonomous-machines/, accessed July 7, 2023.

Appendix A: Product sheet for Hexagon Drive-by-Wire on Chrysler Pacifica

HEXAGON | AUTONOMOUSTUFF

Pacifica DBW Product Sheet
11 February 2022

Drive-by-Wire kit compatible with the Chrysler Pacifica

Get your vehicle on the road quicker and safer with plug-and-play control of throttle, brake, steering & shifting on automotive-grade hardware

The Drive-By-Wire (DBW) kit gives you plug-and-play control of throttle, brake, steering and shifting on a production Chrysler Pacifica vehicle using production hardware from New Eagle. You can interface your AV system with the DBW kit using a ROS interface over CAN.

This kit is an ideal choice for robo-taxi applications due to its spacious, comfortable interior (seats 7) and power doors and hatch (also controllable through kit).

Control features

- Speed control
- Accelerator
- Steering
- PRNDL selector
- Turn signals
- Hazards
- Door/Liftgate
- High-beam headlights
- Front and rear window wipers

Optional

- Ignition
- Horn
- Parking brake

Safety at the forefront

- **Firmware speed limits** ensure safe operation during development (calibratable)
- System continuously **monitors driver inputs** and can **safely transition control** to safety driver
- **Automotive-Grade ruggedized hardware** (IP68, up to 100°C) can withstand harsh environmental conditions

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Feedback

- Vehicle speed
- IMU/Accelerometer
- Accelerator position
- Brake position
- Brake pressure
- ABS-Active flag
- Steering wheel angle
- Steering drive input torque
- Transmission numerical gear
- Turn signal state
- Hazards state
- Door and hood ajar states
- Headlight states
- Wiper states
- 12v System voltage
- Doorlock states
- Airbag deployed states
- Seatbelt states
- Steering wheel button states
- Wheel encoder pulse counters
- Wheel RPMs
- Ambient temperature
- Fuel level
- Ultrasonic park assist sensor distances
- Adaptive cruise radar object distance (optional)
- GPS (optional)
- Tire pressure
- VIN
- Wheel RPMs

Frequently asked questions

- **What models/years are supported?**
  Hybrid, ICE (Optional); 2018, 2019, 2020, 2021

- **Does the system interfere with existing safety systems of the vehicle?**
  No, ABS, ESC, and AEB functions that exist on the base vehicle are not affected and work as provided by OEM.

- **Are there any limitations to the control authority for each actuator?**
  No, New Eagle designs the DBW systems to meet or exceed the human capability to control the vehicle.

- **What type of hardware is used in the system?**
  New Eagle uses automotive grade components on everything from the harness connectors to the actuators (if required) to the supervisory embedded controller.

- **Are there other controls features or data that could be customised or provided?**
  Yes, please inquire with sales team.

Contact Hexagon | AutonomouStuff

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Appendix B: Pre-driving safety checklist

1. Follow OU SOP for vehicle setup (from shore to car power and start-up sequence)
2. Sensors: Verify operation of the LiDAR, cameras, GPS, and RADAR system
    (a) LiDAR: verify the environment around the van is correct and the orientation is correct
    (b) Cameras: do both cameras see the correct direction and are displaying images in RViz
    (c) LiDAR + Camera calibration by AutonomouStuff staff: Run the Autoware LiDAR and Camera overlay process in Rviz
    (d) RADAR: Ensure that objects are detected in front of the vehicle and reflect the environment (Dreamview). Verify data in RViz
    (e) GPS: Check that the GPS system is in RTK mode and receiving correction using the script provided by AutonomouStuff.
3. Drive-by-wire
    (a) Verify operation of the drive-by-wire (DBW) system by using the Logitech controller program and checking for manual control of braking, steering, and throttle systems
4. Maps
    (a) Ensure that the maps are available and loaded by the Apollo system
5. Safety Driver
    (a) Designate safety driver
    (b) Designate operator to inform safety driver of traffic light detection and other autonomous driving failures

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Appendix B7
Data and Key Performance Metrics

#	Topic	Data Topic	Definition	Source	Performance Measures
1	apollo/monitor/system status	system status	The monitor component is responsible for monitoring the health and performance of the various modules and components within the platform. The "System Status" component of the monitor module provides real-time information on the overall health and performance of the platform, including information on the status of the various sensors, cameras, and other components. This information is used to identify any potential issues with the platform and to ensure that the vehicle is operating safely and efficiently.		Disengagement
2	apollo/drive event	drive event	refers to a significant event or occurrence that takes place during the operation of an autonomous vehicle in the APOLLO platform developed by Baidu. Drive events can include various types of incidents, such as collisions, lane departures, or unexpected stops, as well as normal driving scenarios, such as changes in traffic conditions, road features, or other environmental factors. Drive events are used to inform the autonomous vehicle's control system, providing real-time information about the vehicle's environment and the driving situation. The APOLLO/DRIVE EVENT data is collected and analyzed by the platform, providing valuable insights into the performance and behavior of the autonomous vehicle, and enabling continuous improvement and refinement of the technology. Drive events play a crucial role in ensuring the safety and reliability of autonomous vehicles, and are a critical component of the overall APOLLO platform.		Disengagement
3	apollo/hmi/status	status	APOLLO/HMI/STATUS for autonomous vehicles developed by Baidu refers to the Human-Machine Interface (HMI) status of the APOLLO autonomous vehicle platform The HMI status provides information about the current state and operation of the autonomous vehicle, including its mode of operation (e.g. manual, autonomous), the status of its various systems, and any relevant alerts or notifications. The HMI status helps the operator understand the vehicle's behavior and make informed decisions, as well as monitor its performance and ensure safe and reliable operation.		Disengagement
4	apollo/monitor/monitor	monitor	refers to the monitoring system in the APOLLO platform developed by Baidu, used to monitor the state and behavior of an autonomous vehicle. The monitoring system receives data from various sources, including sensors, the control system, and the CANBUS network, and uses this data to monitor the vehicle's performance and ensure safe and efficient operation. The APOLLO/MONITOR/MONITOR system provides real-time information about the vehicle's state and behavior, including information about its speed, position, and orientation, as well as the state of its various systems and components. The monitoring system also generates alerts in case of any anomalies or deviations from normal operation, allowing the control system to take appropriate action to ensure the safety of the vehicle and its passengers.		Disengagement
5	apollo/sensor/gnss/ins status	ins status	INS stands for Inertial Navigation System, which is a navigation system that uses measurements from inertial sensors (accelerometers and gyroscopes) to determine the position, velocity, and orientation of a device in real-time. In an autonomous vehicle or robotics platform, for example, the INS status information may be used by the navigation and control systems to determine the accuracy and reliability of the navigation solution and make decisions on when to switch between different navigation systems or to trigger a fallback to a backup navigation system. The specific data contained in this topic may vary depending on the particular implementation of the Apollo platform, but it could include information about the accuracy and stability of the GNSS and INS sensors, the quality of the navigation solution, and any error or fault conditions that may affect the performance of the navigation system.	https://novatel.com/an-introduction-to-gnss/chapter-6-gnss-ins/gnss-ins-systems https://docs.inertialsense.com/user-manual/com-protocol/DID-descriptions/	Localization Accuracy
6	apollo/sensor/gnss/rtcm data	rtcm data	RTCM stands for Radio Technical Commission for Maritime Services, and is a standards organization that develops and maintains standards for GNSS (Global Navigation Satellite System) navigation systems. RTCM standards define the format and content of GNSS correction and reference data messages that are transmitted from reference stations to GNSS receivers. These correction data messages are used to improve the accuracy of GNSS positioning solutions by correcting for various errors and biases in the GNSS signal. In addition to correction data, RTCM standards also define messages for other GNSS-related information, such as time-of-week, ionosphere delay, and more. RTCM standards are widely used in GNSS navigation applications, particularly in the maritime, aviation, and surveying industries. RTCM provides a common and standardized format for GNSS correction and reference data, allowing GNSS receivers from different manufacturers to receive and use the same correction data. This helps to ensure compatibility and interoperability between different GNSS receivers and reference stations, and makes it easier to implement and deploy GNSS-based navigation solutions.	https://docs.novatel.com/OEM7/Content/Logs/RTCMV3_Standard_Logs.htm?tocpath=Commands%20%2526%20Logs%7CLogs%7CGNSS%20Logs%7C_____164	Localization Accuracy

#	Topic	Data Topic	Definition	Source	Performance Measures
7	apollo/sensor/gnss/gnss status	gnss status	The specific information contained in this topic may vary depending on the particular implementation of the Apollo platform, but it could include data such as the number of visible satellites, the accuracy of the GNSS solution, and any error or fault conditions that may affect the performance of the GNSS system.	https://docs.novatel.com/OEM7/Content/Logs/RXSTATUS.htm?Highlight=gnss%20status#Table_ReceiverStatus	Localization Accuracy
8	apollo/sensor/gnss/stream status	stream status	The GNSS data stream provides real-time positioning information, including satellite signals and navigation parameters, used by the autonomous vehicle's navigation and control systems. The stream status provides information about the quality and availability of the GNSS data, and is used to monitor and diagnose GNSS performance issues, as well as to ensure that the autonomous vehicle's navigation system is working correctly and accurately. The APOLLO/SENSOR/GNSS/STREAM STATUS is an important aspect of the overall monitoring and control of the autonomous vehicle, and helps to ensure safe and reliable operation.	https://docs.novatel.com/OEM7/Content/Logs/RTCMV3_Standard_Logs.htm?Highlight=gnss%20stream	Localization Accuracy
9	apollo/sensor/gnss/rtk_eph	rtk_eph	RTK and EPH are terms used in GNSS (Global Navigation Satellite System) navigation and positioning. RTK stands for Real-Time Kinematic, and refers to a high-precision GNSS positioning technique that uses measurements from both the GNSS receiver and a reference station to calculate a position solution in real-time. RTK provides sub-decimeter level accuracy for GNSS positioning, making it suitable for applications that require high precision, such as autonomous vehicles. EPH stands for Ephemeris, which is a set of parameters that describe the precise location and motion of a GNSS satellite in orbit. The ephemeris data is transmitted by the GNSS satellite and received by the GNSS receiver. The receiver uses the ephemeris data to calculate its position and velocity relative to the GNSS satellite. In summary, RTK is a high-precision GNSS positioning technique, and EPH is a set of parameters that describe the precise location and motion of a GNSS satellite. Both RTK and EPH are important components in GNSS navigation and positioning systems, particularly in applications that require high accuracy.	https://docs.novatel.com/OEM7/Content/Logs/RTKPOS.htm?Highlight=RTK	Localization Accuracy
10	apollo/sensor/gnss/ins stat	ins stat	The specific information contained in this topic may vary depending on the particular implementation of the Apollo platform, but it could include data such as the accuracy and stability of the GNSS and INS sensors, the quality of the navigation solution, and any error or fault conditions that may affect the performance of the navigation system.	https://novatel.com/an-introduction-to-gnss/chapter-6-gnss-ins/gnss-ins-systems https://docs.inertialsense.com/user-manual/com-protocol/DID-descriptions/	Localization Accuracy
11	apollo/sensor/gnss/best pose	best pose	refers to the best estimated position of an autonomous vehicle, as determined by the Global Navigation Satellite System (GNSS) in the APOLLO platform developed by Baidu. The best pose is a combination of GNSS measurements and other sensor data, such as cameras, lidars, and IMUs, that are fused to provide the most accurate estimate of the vehicle's position and orientation. The best pose is critical for navigation and control of the autonomous vehicle, and is used to make decisions about vehicle motion, such as path planning and control, and to provide a reliable estimate of the vehicle's location for mapping and localization. The APOLLO/SENSOR/GNSS/BEST POSE is an important aspect of the autonomous vehicle's overall performance and safety, and is continuously updated to provide the most accurate and up-to-date information.	https://docs.novatel.com/OEM7/Content/Logs/BESTPOS.htm?tocpath=Commands%20%2526%20Logs%7CLogs%7CGNSS%20Logs%7C_____20	Localization Accuracy
12	apollo/sensor/gnss/heading	heading	refers to the heading, or direction of travel, of an autonomous vehicle as determined by the Global Navigation Satellite System (GNSS) in the APOLLO platform developed by Baidu. The heading is an important aspect of the vehicle's position and orientation, and is used for navigation, control, and mapping. The GNSS system provides information about the vehicle's heading, based on the measurement of satellite signals, as well as other sensor data, such as inertial measurement units (IMUs) and wheel encoders, that are fused to provide the most accurate estimate of the vehicle's orientation.	https://docs.novatel.com/OEM7/Content/Logs/HEADING2.htm?tocpath=Commands%20%2526%20Logs%7CLogs%7CGNSS%20Logs%7C_____74	Localization Accuracy
13	apollo/sensor/gnss/raw data	raw data	GNSS is a system of satellites that provides real-time positioning information for autonomous vehicles. The raw data from the GNSS sensor includes signals from GNSS satellites, as well as information about the satellite orbit, clock offset, and other parameters that are used to calculate the vehicle's position and orientation. The APOLLO/SENSOR/GNSS/RAW DATA is an important component of the autonomous vehicle's navigation system, and is used to determine the vehicle's position and orientation with high accuracy. The raw data is processed and fused with other sensor data, such as cameras, lidars, and IMUs, to provide a comprehensive and accurate estimate of the vehicle's state.	https://docs.novatel.com/OEM7/Content/SPAN_Logs/RAWIMU.htm?Highlight=raw%20data	Localization Accuracy

#	Topic	Data Topic	Definition	Source	Performance Measures
14	apollo/localization/msf status	msf status	"Apollo/localization/msf status" refers to a component of the Apollo autonomous vehicle platform developed by Baidu. "Localization" is the process of determining the position and orientation of a vehicle in an environment. This is a critical component of autonomous driving, as the vehicle needs to know its location in order to make informed decisions about its motion and behavior. "MSF" likely stands for Multi-Sensor Fusion, which refers to the process of combining information from multiple sensors, such as cameras, LIDARs, and radars, to improve the accuracy and robustness of the localization.		Localization Accuracy
15	apollo/localization/pose	pose	The localization module is responsible for determining the vehicle's position and orientation in the world, and the pose estimation component of the localization module is responsible for estimating the vehicle's pose, or its position and orientation relative to a reference frame. This information is used to build an accurate map of the vehicle's surroundings and is critical for tasks such as path planning and obstacle avoidance. By accurately estimating the vehicle's pose, the Apollo platform can ensure that the vehicle moves safely and efficiently through its environment.		Localization Accuracy
16	apollo/sensor/gnss/rtk obs	rtk obs	refers to Real-Time Kinematic (RTK) observations obtained from Global Navigation Satellite System (GNSS) sensors, likely within the context of the APOLLO platform developed by OpenAI. RTK is a GNSS positioning technique that provides centimeter-level accuracy by using real-time corrections from a reference station or network.	https://docs.novatel.com/OEM7/Content/Logs/RTKPOS.htm?Highlight=rtk%20eph	Localization Accuracy
17	apollo/sensor/gnss/imu/tf	imu/tf	"tf" in the topic name is likely an abbreviation for "transform", which in ROS refers to a mathematical representation of a coordinate transformation between two coordinate frames. In the context of the Apollo platform, this topic could be used to provide information on the relative position and orientation of the GNSS and IMU sensors.	https://docs.novatel.com/OEM7/Content/SPAN_Logs/RAWIMUS.htm?Highlight=imu%20data	Localization Accuracy Motion Control
18	apollo/sensor/gnss/corrected imu	corrected imu	CORRIMUDATA log contains the raw IMU data corrected for gravity, the earth's rotation and estimated sensor errors.	https://docs.novatel.com/OEM7/Content/SPAN_Logs/CORRIMUDATA.htm?Highlight=imu%20data	Localization Accuracy Motion Control
19	apollo/sensor/gnss/odometry	odometry	GNSS (Global Navigation Satellite System) is a system of satellites that provides location and time information to users on Earth. ODOMETRY is a method of estimating a vehicle's position and orientation based on its linear and angular motion, typically using data from wheel encoders, inertial measurement units (IMUs), or other sensors. By combining GNSS measurements with odometry, a more accurate estimate of the vehicle's pose can be obtained, especially in environments where GNSS signals are weak or unavailable.	https://anavs.com/knowledgebase/tightly-coupled-position-determination-with-visual-odometry-gnss-wheel-odometry-and-imu/	Localization Accuracy Motion Control
20	apollo/canbus/chassis details	chassis details	"Apollo/canbus/chassis details" refers to a component of the Apollo autonomous vehicle platform developed by Baidu. CAN bus (Controller Area Network bus) is a type of communication protocol used in vehicles to allow various electronic systems and devices to communicate with each other. In an autonomous vehicle, the CAN bus is used to exchange information between the various systems and components, such as the engine control unit, the brake system, and the steering system. "Apollo/canbus/chassis details" likely refers to the specific information related to the chassis of the vehicle that is transmitted via the CAN bus. This information can include the vehicle's speed, wheel speeds, suspension data, and other details related to the vehicle's chassis. In the Apollo platform, the "Apollo/canbus/chassis details" component provides access to the information transmitted over the CAN bus that is specific to the vehicle's chassis. This information is used by other components of the platform, such as the perception, planning, and control systems, to make informed decisions about the vehicle's motion and behavior.		Motion Control
21	apollo/control/pad	pad	"Apollo/Control/Pad" refers to the control interface or system used in the Apollo autonomous driving platform developed by Baidu. The platform provides various modules for different tasks in autonomous driving, such as perception, prediction, control, planning, and more. The control module is responsible for executing the decisions made by the platform's planning and decision-making components, such as steering, accelerating, and braking the vehicle. The "Pad" part of the phrase likely refers to the interface through which a human operator can input commands or control the vehicle manually, if necessary. This interface could take the form of a touch screen or physical control pad. These control capabilities are critical for ensuring the safe and efficient operation of autonomous vehicles.		Motion Control

#	Topic	Data Topic	Definition	Source	Performance Measures
22	apollo/canbus/chassis	chassis	refers to the communication network in the APOLLO platform developed by Baidu, used to monitor and control the various systems and components of an autonomous vehicle. CANBUS, or Controller Area Network bus, is a data communication protocol widely used in the automotive industry. The APOLLO/CANBUS/CHASSIS network is used to transmit data between the vehicle's control system and its various subsystems, such as the powertrain, suspension, and brakes. The CANBUS/CHASSIS network provides real-time information about the state of the vehicle's various systems and components, enabling the control system to make informed decisions about vehicle motion and behavior.		Motion Control
23	apollo/control/control	control	refers to the control system in the APOLLO platform developed by Baidu, used to regulate the motion and behavior of an autonomous vehicle. The control system receives inputs from various sensors, such as cameras, lidars, and GNSS, as well as information from the CANBUS network, and uses this information to make decisions about vehicle motion and behavior. The APOLLO/CONTROL system implements algorithms that determine the vehicle's trajectory, speed, and other control parameters, based on real-time information about the vehicle's environment, road conditions, and other factors. The control system also monitors the vehicle's state and behavior, and makes adjustments as needed to ensure safe and efficient operation.		Motion Control
24	apollo/sensor/camera/front 6 mm image	front 6mm image	An Apollo front 6mm camera image refers to an image captured by a front-facing camera in the Apollo autonomous vehicle platform developed by Baidu. The "6mm" in the name refers to the focal length of the camera lens, which determines the field of view and perspective of the image. In autonomous driving, cameras are used to provide visual information about the environment, such as detecting obstacles, recognizing traffic signals, and performing lane detection. The front 6mm camera in the Apollo platform is likely used for tasks such as obstacle detection, which requires a wide field of view to detect potential hazards in front of the vehicle.		Object Detection
25	apollo/prediction/perception obstacles	perception obstacles	"Apollo/prediction/perception obstacles" refers to the process of predicting and perceiving obstacles in an autonomous driving platform, specifically the Apollo platform developed by Baidu. Perception is a crucial component of autonomous vehicles that involves processing sensory data from cameras, LIDARs, radars, and other sensors to understand the environment and detect objects. Obstacle prediction involves estimating the future position of obstacles based on their current motion and trajectory. In the Apollo platform, perception obstacles refer to the detected objects in the environment that could potentially pose a threat or hinder the vehicle's motion. The prediction component of "Apollo/prediction/perception obstacles" involves anticipating the future position and motion of these obstacles and taking appropriate actions to avoid them.		Object Detection
26	apollo/sensor/camera/front 25 mm image	front 25 mm image	The "Front 25 mm Image" likely refers to a specific camera mounted on the front of the vehicle with a 25 mm focal length lens, which is used to capture images of the road ahead and the environment surrounding the vehicle. These images are processed by the platform's perception module to detect and recognize objects in the vehicle's surroundings, such as other vehicles, pedestrians, road signs, and more. This information is then used by the platform's decision-making and control components to ensure the safe and efficient operation of the vehicle. The front 25 mm camera is just one component of the suite of sensors and cameras used by the Apollo autonomous driving platform. The information captured by this camera is used in conjunction with data from other sensors to build a complete and accurate representation of the vehicle's surroundings. The data captured by the front 25 mm camera is crucial for tasks such as object detection, lane detection, and traffic sign recognition, which are critical for the safe operation of autonomous vehicles. Additionally, the resolution and quality of the images captured by the front 25 mm camera play a key role in determining the accuracy and reliability of the perception module's outputs. The Apollo platform is designed to support high-precision, high-reliability autonomous driving, and the front 25 mm camera is an important component in achieving this goal.		Object Detection
27	apollo/sensor/velodyne32/point cloud 2	point cloud 2	A Velodyne 32 is a type of 3D LIDAR (Light Detection and Ranging) sensor that uses laser beams to measure distance and generate a 3D point cloud of the environment. The "32" in the name refers to the number of laser beams used. Point Cloud 2 is a widely used data format for representing 3D data, particularly in the fields of robotics and computer vision. It stores a set of points in 3D space, along with additional information such as color and reflectivity.	https://velodynelidar.com/	Object Detection

#	Topic	Data Topic	Definition	Source	Performance Measures
28	apollo/perception/traffic light	traffic light	refers to the traffic light detection and recognition system in the APOLLO platform developed by Baidu. This system uses data from various sensors, such as cameras, lidars, and radar, to detect and recognize traffic lights and road signs in the environment of an autonomous vehicle. The APOLLO/PERCEPTION/TRAFFIC LIGHT system processes the sensor data in real-time, and generates information about the location, color, and state of the traffic lights and road signs, as well as their expected behavior and timing. The system is a critical component of the autonomous vehicle's perception system, and plays a key role in ensuring safe and efficient operation of the vehicle. The traffic light information generated by the system is used by the control system to make informed decisions about the vehicle's motion and behavior, and to ensure that the vehicle complies with traffic laws and regulations.		Object Detection
29	apollo/sensor/velodyne32/velodyne scan	velodyne scan	A Velodyne scan refers to the 3D data generated by a Velodyne LIDAR sensor. It represents a set of points in 3D space, captured at a certain moment in time, that provides a snapshot of the environment around the sensor. A Velodyne scan can be processed and used for various tasks in autonomous driving, such as obstacle detection, mapping, and localization. The Velodyne 32 LIDAR sensor specifically uses 32 laser beams to generate its point cloud, providing a dense and accurate representation of the environment.	https://velodynelidar.com/	Object Detection
30	apollo/perception/obstacles	obstacles	refers to the obstacle detection and tracking system in the APOLLO platform developed by Baidu. This system uses data from various sensors, such as cameras, lidars, and radar, to detect and track obstacles in the environment of an autonomous vehicle, including other vehicles, pedestrians, bicycles, and static obstacles such as buildings and trees. The APOLLO/PERCEPTION/OBSTACLES system processes the sensor data in real-time, and generates information about the location, size, shape, and motion of the obstacles, as well as their predicted behavior and trajectory. The system is a critical component of the autonomous vehicle's perception system, and plays a key role in ensuring safe and efficient operation of the vehicle. The obstacle information generated by the system is used by the control system to make informed decisions about the vehicle's motion and behavior, and to avoid collisions and other hazardous situations.		Object Detection
31	apollo/planning/planning	planning	"Apollo/planning/planning" refers to the process of generating a plan of action for an autonomous vehicle in the Apollo platform developed by Baidu. Planning is a key component of autonomous driving that involves deciding the optimal path and actions for the vehicle to take based on its current state, the environment, and the goals of the system. It considers factors such as the current position and velocity of the vehicle, the position of obstacles and other vehicles, traffic rules and regulations, and the desired destination. In the Apollo platform, "Apollo/planning/planning" refers to the process of generating a plan of action for the vehicle to follow, taking into account the current state of the vehicle and the environment. The planning component of the platform uses information from perception, prediction, and other modules to generate a safe and efficient plan for the vehicle to follow.		Planning
32	apollo/routing response history/tf static	tf static	"Apollo/routing response history/tf static" refers to a combination of functional components in the Apollo autonomous vehicle platform developed by Baidu. "Routing response history" likely refers to a record or log of the vehicle's responses to routing requests, which specify the desired path for the vehicle to follow. This history can be used to evaluate the performance of the vehicle and the routing algorithm, and to improve the system over time. "tf static" likely refers to the static part of a Transform library in robotics, specifically in the context of the Robot Operating System (ROS). A Transform library is used to represent the relative positions of objects in a 3D environment. The "tf static" component specifically refers to the static parts of the environment, such as the position and orientation of landmarks or obstacles, that do not change over time. In the Apollo platform, "Apollo/routing response history/tf static" likely refers to a combination of functionalities related to routing the vehicle and representing the static parts of the environment in a 3D coordinate system. The routing response history component is used to evaluate the performance of the vehicle, while the tf static component provides a means of representing the static parts of the environment in a compact and efficient form.		Planning

#	Topic	Data Topic	Definition	Source	Performance Measures
33	apollo/routing request/routing request	routing request	The routing request component is responsible for determining the optimal route for the vehicle to follow based on its destination, current location, and the state of the road network. The component takes into account factors such as traffic conditions, road closures, and road conditions to determine the most efficient and safe route for the vehicle to follow. These routing capabilities are critical for ensuring the safe and efficient operation of autonomous vehicles.		Planning
34	apollo/prediction/prediction	prediction	refers to the prediction system in the APOLLO platform developed by Baidu, used to anticipate the future behavior of objects in the environment of an autonomous vehicle. The prediction system uses data from various sensors, such as cameras, lidars, and GNSS, as well as information from maps and other sources, to generate predictions about the future locations, motions, and behaviors of other vehicles, pedestrians, and other objects in the environment. The APOLLO/PREDICTION/PREDICTION system is a critical component of the autonomous vehicle's safety and decision-making systems, and plays a key role in ensuring safe and efficient operation of the vehicle. The predictions generated by the system are used to inform the vehicle's control system, enabling it to make informed decisions about vehicle motion and behavior in real-time.		Planning
35	apollo/navigation/navigation	navigation	refers to the navigation system in the APOLLO platform developed by Baidu. This system is responsible for determining the optimal path and control actions for an autonomous vehicle to reach its destination. The APOLLO/NAVIGATION system receives input from various sources, including the perception system, which provides information about the vehicle's environment and obstacles, and the map and localization system, which provides information about the vehicle's position and orientation. Based on this information, the APOLLO/NAVIGATION system generates a path and a set of control actions for the vehicle to follow. The navigation system is a critical component of the autonomous vehicle's control system, and plays a key role in ensuring safe and efficient operation of the vehicle. The APOLLO/NAVIGATION system continuously updates its path and control actions based on new information from the perception system and the map and localization system, and adjusts the vehicle's behavior to respond to changing conditions and unexpected events.		Planning
36	apollo/common/latency reports	latency reports	Latency is a measure of the time it takes for a system or process to respond to a request or input. In the context of autonomous vehicles, latency records are used to monitor the performance of various systems and processes, including sensor data processing, decision-making algorithms, and actuator response. The records are used to identify and track the sources of latency, and to optimize the system to minimize latency and improve overall performance and safety. The latency records in the APOLLO platform provide valuable information to developers, researchers, and operators, enabling them to continuously improve and refine the autonomous driving technology.		Planning Motion Control
37	apollo/common/latency records	latency records	refers to the measurement of the time delay, or latency, in the APOLLO platform developed by Baidu, between the input of sensor data and the output of control commands. Latency records are used to monitor the performance of the autonomous vehicle's control system, and to identify areas where improvements can be made to reduce latency and improve overall system performance. The latency records track the time taken for sensor data to be processed, transmitted, and acted upon by the control system, and provide a measure of the responsiveness of the system.	https://github.com/ApolloAuto/apollo/tree/master/modules/common#latency_recorder	Planning Motion Control
38	apollo/routing response/velodyne scan	velodyne scan	A Velodyne scan refers to the 3D data generated by a Velodyne LIDAR sensor. It represents a set of points in 3D space, captured at a certain moment in time, that provides a snapshot of the environment around the sensor. A Velodyne scan can be processed and used for various tasks in autonomous driving, such as obstacle detection, mapping, and localization. The Velodyne 32 LIDAR sensor specifically uses 32 laser beams to generate its point cloud, providing a dense and accurate representation of the environment.		Planning Object Detection

Performance Measures and Key Performance Indicators

The Apollo data element names in each row and applicable key performance indicators (KPI) within project performance measures. Orange shaded cells indicate KPIs that were calculated using data collected on the vehicles during ADS deployments.

Performance Measures & KPIs

#	Data (Rostopics)	Disengagements: Instances of manual intervention	Instances of system disengagements	Rate of disengagements	Reasons for Disengagement	Autonomous Miles Between Disengagements
1	apollo/monitor/system status					
2	apollo/drive event					
3	apollo/hmi/status					
4	apollo/monitor/monitor					
5	apollo/sensor/gnss/ins status					
6	apollo/sensor/gnss/rtcm data					
7	apollo/sensor/gnss/gnss status					
8	apollo/sensor/gnss/stream status					
9	apollo/sensor/gnss/rtk_eph					
10	apollo/sensor/gnss/ins stat					
11	apollo/sensor/gnss/best pose					
12	apollo/sensor/gnss/heading					
13	apollo/sensor/gnss/raw data					
14	apollo/localization/msf status					
15	apollo/localization/pose					
16	apollo/sensor/gnss/rtk obs					
17	apollo/sensor/gnss/imu/tf					
18	apollo/sensor/gnss/corrected imu					
19	apollo/sensor/gnss/odometry					
20	apollo/canbus/chassis details					
21	apollo/control/pad					
22	apollo/canbus/chassis					
23	apollo/control/control					
24	apollo/sensor/camera/front 6 mm image					
25	apollo/prediction/perception obstacles					
26	apollo/sensor/camera/front 25 mm image					
27	apollo/sensor/velodyne32/point cloud 2					
28	apollo/perception/traffic light					
29	apollo/sensor/velodyne32/velodyne scan					
30	apollo/perception/obstacles					
31	apollo/planning/planning					
32	apollo/routing response history/tf static					
33	apollo/routing request/routing request					
34	apollo/prediction/prediction					
35	apollo/navigation/navigation					
36	apollo/common/latency reports					
37	apollo/common/latency records					
38	apollo/routing response/velodyne scan					

#	Data (Rostopics)	Localization Accuracy: Localization Accuracy	Lane Level Localization Accuracy	Localization Reliability	Map Data Accuracy	Positioning System Uptime	GPS Operational State	GPS Standard Deviation	Number of Satellites	Robustness to Signal Loss	RTK Operational State	Reasons for GNSS Loss	Environmental Adaptability
1	apollo/monitor/system status												
2	apollo/drive event												
3	apollo/hmi/status												
4	apollo/monitor/monitor												
5	apollo/sensor/gnss/ins status												
6	apollo/sensor/gnss/rtcm data												
7	apollo/sensor/gnss/gnss status												
8	apollo/sensor/gnss/stream status												
9	apollo/sensor/gnss/rtk_eph												
10	apollo/sensor/gnss/ins stat												
11	apollo/sensor/gnss/best pose												
12	apollo/sensor/gnss/heading												
13	apollo/sensor/gnss/raw data												
14	apollo/localization/msf status												
15	apollo/localization/pose												
16	apollo/sensor/gnss/rtk obs												
17	apollo/sensor/gnss/imu/tf												
18	apollo/sensor/gnss/corrected imu												
19	apollo/sensor/gnss/odometry												
20	apollo/canbus/chassis details												
21	apollo/control/pad												
22	apollo/canbus/chassis												
23	apollo/control/control												
24	apollo/sensor/camera/front 6 mm image												
25	apollo/prediction/perception obstacles												
26	apollo/sensor/camera/front 25 mm image												
27	apollo/sensor/velodyne32/point cloud 2												
28	apollo/perception/traffic light												
29	apollo/sensor/velodyne32/velodyne scan												
30	apollo/perception/obstacles												
31	apollo/planning/planning												
32	apollo/routing response history/tf static												
33	apollo/routing request/routing request												
34	apollo/prediction/prediction												
35	apollo/navigation/navigation												
36	apollo/common/latency reports												
37	apollo/common/latency records												
38	apollo/routing response/velodyne scan												

#	Data (Rostopics)	Object Detection: Total Objects Detected	Longitudinal Detection Failures	Lateral Detection Failures	Non-Reactive Instances to VRUs/Objects	False Positives per X Miles **(X will be determined based on average deployment run distance)**	ID Switching Errors	Detection Accuracy	False Positive Rate	False Negative Rate	Detection Latency	Classification Accuracy	Range of Detection	Coverage Area	Object Tracking Consistency	Detection Reliability Under Adverse Conditions
1	apollo/monitor/system status															
2	apollo/drive event															
3	apollo/hmi/status															
4	apollo/monitor/monitor															
5	apollo/sensor/gnss/ins status															
6	apollo/sensor/gnss/rtcm data															
7	apollo/sensor/gnss/gnss status															
8	apollo/sensor/gnss/stream status															
9	apollo/sensor/gnss/rtk_eph															
10	apollo/sensor/gnss/ins stat															
11	apollo/sensor/gnss/best pose															
12	apollo/sensor/gnss/heading															
13	apollo/sensor/gnss/raw data															
14	apollo/localization/msf status															
15	apollo/localization/pose															
16	apollo/sensor/gnss/rtk obs															
17	apollo/sensor/gnss/imu/tf															
18	apollo/sensor/gnss/corrected imu															
19	apollo/sensor/gnss/odometry															
20	apollo/canbus/chassis details															
21	apollo/control/pad															
22	apollo/canbus/chassis															
23	apollo/control/control															
24	apollo/sensor/camera/front 6 mm image															
25	apollo/prediction/perception obstacles															
26	apollo/sensor/camera/front 25 mm image															
27	apollo/sensor/velodyne32/point cloud 2															
28	apollo/perception/traffic light															
29	apollo/sensor/velodyne32/velodyne scan															
30	apollo/perception/obstacles															
31	apollo/planning/planning															
32	apollo/routing response history/tf static															
33	apollo/routing request/routing request															
34	apollo/prediction/prediction															
35	apollo/navigation/navigation															
36	apollo/common/latency reports															
37	apollo/common/latency records															
38	apollo/routing response/velodyne scan															

#	Data (Rostopics)	Planning: Car Following Distance Violations	Time to Collision Threshold Breaches	Intersection Handling Success Rate	Adherence to Speed Limits	Tactical Decision Making Accuracy	Response to Traffic Signals Compliance	Road Rules Violations	Reasons for Road Rules Violations
1	apollo/monitor/system status								
2	apollo/drive event								
3	apollo/hmi/status								
4	apollo/monitor/monitor								
5	apollo/sensor/gnss/ins status								
6	apollo/sensor/gnss/rtcm data								
7	apollo/sensor/gnss/gnss status								
8	apollo/sensor/gnss/stream status								
9	apollo/sensor/gnss/rtk_eph								
10	apollo/sensor/gnss/ins stat								
11	apollo/sensor/gnss/best pose								
12	apollo/sensor/gnss/heading								
13	apollo/sensor/gnss/raw data								
14	apollo/localization/msf status								
15	apollo/localization/pose								
16	apollo/sensor/gnss/rtk obs								
17	apollo/sensor/gnss/imu/tf								
18	apollo/sensor/gnss/corrected imu								
19	apollo/sensor/gnss/odometry								
20	apollo/canbus/chassis details								
21	apollo/control/pad								
22	apollo/canbus/chassis								
23	apollo/control/control								
24	apollo/sensor/camera/front 6 mm image								
25	apollo/prediction/perception obstacles								
26	apollo/sensor/camera/front 25 mm image								
27	apollo/sensor/velodyne32/point cloud 2								
28	apollo/perception/traffic light								
29	apollo/sensor/velodyne32/velodyne scan								
30	apollo/perception/obstacles								
31	apollo/planning/planning								
32	apollo/routing response history/tf static								
33	apollo/routing request/routing request								
34	apollo/prediction/prediction								
35	apollo/navigation/navigation								
36	apollo/common/latency reports								
37	apollo/common/latency records								
38	apollo/routing response/velodyne scan								

#	Data (Rostopics)	Motion Control: Steering Precision	Braking Smoothness	Acceleration Smoothness	Adherence to Acceleration Limits	Lateral Control Stability	Energy Efficiency of Motion Control
1	apollo/monitor/system status						
2	apollo/drive event						
3	apollo/hmi/status						
4	apollo/monitor/monitor						
5	apollo/sensor/gnss/ins status						
6	apollo/sensor/gnss/rtcm data						
7	apollo/sensor/gnss/gnss status						
8	apollo/sensor/gnss/stream status						
9	apollo/sensor/gnss/rtk_eph						
10	apollo/sensor/gnss/ins stat						
11	apollo/sensor/gnss/best pose						
12	apollo/sensor/gnss/heading						
13	apollo/sensor/gnss/raw data						
14	apollo/localization/msf status						
15	apollo/localization/pose						
16	apollo/sensor/gnss/rtk obs						
17	apollo/sensor/gnss/imu/tf						
18	apollo/sensor/gnss/corrected imu						
19	apollo/sensor/gnss/odometry						
20	apollo/canbus/chassis details						
21	apollo/control/pad						
22	apollo/canbus/chassis						
23	apollo/control/control						
24	apollo/sensor/camera/front 6 mm image						
25	apollo/prediction/perception obstacles						
26	apollo/sensor/camera/front 25 mm image						
27	apollo/sensor/velodyne32/point cloud 2						
28	apollo/perception/traffic light						
29	apollo/sensor/velodyne32/velodyne scan						
30	apollo/perception/obstacles						
31	apollo/planning/planning						
32	apollo/routing response history/tf static						
33	apollo/routing request/routing request						
34	apollo/prediction/prediction						
35	apollo/navigation/navigation						
36	apollo/common/latency reports						
37	apollo/common/latency records						
38	apollo/routing response/velodyne scan						

Appendix B8
TRC ADS Project Deployment Interview

1. What is your general impression of the automated vehicle technology used on the three Athens routes while in automated mode?

At first, constantly want to take control, but then you get used to it and it becomes nice, but the more you drive you find downfalls since it's not a completed system yet – you must always be aware of your surroundings.
The system is better at lower speeds and when going faster the limitations of the vehicle come into play. It gets interesting when engaging and taking corners. You have to get to know the system, but then you get comfortable.

a. What features were useful?

- Longitudinal control was helpful because it allowed the driver's attention to be focused on the surroundings and environment rather than the speed.
- Vehicle reacted to the predicted path of the surrounding vehicles.

b. What features were not useful?

The range of object detection was insufficient above certain speed thresholds, as well as performance being dependent on the extent of other vehicles and pedestrians present. This was particularly important to be ready to respond by disengaging at traffic lights depending on how many cars were stopped and how fast the approach was.

c. How easy was it to engage the system?

The actuation required for engagement was relatively easy, but meeting the conditions for engagement was a little trickier. The conditions for engagement which must be met included having a route planned and traveling as close to the center of that route as possible, without requiring any longitudinal or latitudinal input from the driver, because those were methods of disengagement. There also tended to be a delay between the system's response to the driver's actuation of engagement, so if the route was curvy or hilly or windy or otherwise influenced into drifting from the path, the engagement had a much higher likelihood of failing as it corrected rather severely to the planning, resulting in a potentially jarring experience very much ill-advised in best driving practices of avoiding sudden corrections when possible.

d. What were the general limitations of the technology?

The system performed most reliably at lower speeds. At higher relative speeds object detection would not be within range for an appropriate system response, and required disengagement for manual maneuvering by the driver for the situation.

e. What were the technology operating challenges?

The technology was under-spec'd for the degree of challenges we experienced in the real world. Sensor, processor, and storage limitations required process adjustments which increased the number of disengagements and reduced the quality/consistency of the data.

f. What were the roadway challenges?

The rural areas were curvy and hilly, with relatively narrow roadways and often very little shoulders. The more urban areas often had parking areas and/or pedestrian traffic very near to the roadway which also limited the room for latitudinal error.

2. What are your thoughts on other drivers' behavior around the automated vehicle while in automated mode?

Driver response to the vans was relatively low, notably because the sensor technology on the transit vans looked similar enough to other transit vans outfitted with a variety of work-specific devices, and was less noticeable than the LiDAR mounted on the Fusion.
In automated mode, the vehicle is programmed to respond in a specific way to the input from the sensors, while the range of behavior of other vehicles varied. There were several times that the behavior of surrounding vehicles misaligned with the automated programming, which could not be adjusted to the circumstances which a human driver likely would adjust their typical behavior, thus requiring disengagement for human adjustment. For speed and intersections especially, many disengagements were taken specifically to manually operate the vehicle in a manner more likely to be expected from other drivers.

a. How is this different on rural roads versus urban/suburban roads?

The difference in response didn't seem to do so much with rural versus urban areas, but more related to the relative speed – which is to say at lower speeds both pedestrians and surrounding vehicles would have more time to make observations of the test vehicles and notice the difference in them to what they'd expect from normal traffic in the area.

As far as general behaviors not specific to the autonomous technology, rural drivers have a familiarity with the routes they travel and can tend to relax in their adherence to roadway constraints. Urban/suburban drivers tend to follow a stricter pattern of behaviors to fit the flow of increased traffic. In both cases, outliers can become frustrating, which was observed first-hand on several occasions.

3. Were there changes in automated mode performance between the test track/private road and public roads?

There were several elements of the public roads which could not be sufficiently replicated in the test track/private road conditions, especially involving large quantities of objects, and the curvy/hilly nature of the roadways themselves. The system could not be fully challenged under CE conditions, but gave a basic understanding of autonomous behaviors which could be extrapolated towards application on public roads.

4. What were the operating challenges with the vehicles used in the field deployment?

    a. What were the challenges with the technology in automated mode?

- System limitations (sensor range, hardware components) limiting performance under real-world conditions (including speed, quantity of objects)
- Traffic light positioning variance and range relative to stop bar location as well as how other traffic typically behaved under those conditions, which were unique for each intersection, and adjusting the cameras and sensors to fully encompass that range as well as to remain in adjustment. Also stop and yield sign control and programming on a sloped roadway and the way the system's longitudinal and latitudinal controls were designed to handle those situations. On a different route, all these things could require tuning to be further expanded, again pushing the inherent limitations of the cameras and sensors. The process of confirming and adjusting the calibration of the sensors could not be performed on-the-fly, and required confirmation of the full routes, which only then could be checked against a known standard. Even with proper calibration, accurate traffic light detection was not infallible, thus requiring a specific indicator by simple dash-mounted LED to aid the driver with recognizing the need for a timely disengagement to avoid adverse system behavior.

- Other driver behaviors differing from the system's standard programming with no adjustability, requiring manual takeover to provide the adaptation necessary for surrounding traffic behavior in the situation.

b. What was the most prevalent type of disengagement the system experienced?

Most prevalent type of system disengagement was Other/Unknown, because it wasn't always immediately apparent why the system couldn't continue in autonomous mode, but after returning to autonomous mode following the application of additional safety thresholds, both the steering rate and a drop of data stream over a period of time were determined necessary in order to mitigate risks. This is demonstrated by the Disengagement Type, Figure 46 in section 4.6.1 of TRC's final report.

c. How often did you have to disengage the system manually?

This question is best answered quantitatively by the analysis, but generally manual disengagement by the driver was much more prevalent than autonomous disengagement by the system.

d. What were the most common reasons for disengagement?

Also demonstrated by Disengagement Type, Figure 46 in section 4.6.1 of TRC's final report is that the most common intentional disengagements involved localization (the path of the vehicle strayed too far from intended due to loss of GPS and/or cellular signal for corrections), object detection (something outside the vehicle presented a potential risk), and traffic fault (the behaviors of surrounding traffic warranted manual override of the system's standard autonomous operation).

5. Are there any missing features in the automated vehicle technology while in automated mode?

It would be helpful if the drivers/operators could apply any adjustment for traffic conditions - autonomous mode doesn't consider whether there are a lot of outside factors or none at all, but driving behaviors are typically adjusted for these considerations, and others.

6. What are your thoughts on the reliability and consistency of the automated vehicle technology while in automated mode?

a. How reliable was the system when starting?

The system was relatively reliable once up and running. There were occasional times when modules would need to be restarted at the beginning or in the middle of a run, but that was the exception not the rule.

b. How easy was it to engage the system?

The actual engagement was very easy – pushing a button on the steering wheel - but the preparation for doing so was critical. Procedure started while still in park to plan the route by manually placing points along the route on the map visualized in Dreamview, which would result in a red line representing the path of travel in the center of the lane and through intersections. Recording data would start at the beginning of the route, and once driving along that path, a blue planned route would be generated by the system, highlighting the red line. Typically within 50 yards of the start point, while the blue planned path directly aligned with the red line, engagement by driver input (actuating the button on the steering wheel) could occur. If the blue plan was off-center from the red, the system could severely correct, or jerk, to get on-path as quickly as possible. It was also best practice to engage in a straight, flat area because the system delay between actuation and response could result in slight drift from the path, since any longitudinal or latitudinal input by the driver also served as a disengagement trigger.

7. What are your thoughts/conclusions on driver attentiveness while in automated vehicle mode?

The driver has to be alert and ready to take over all of the time. There were several events experienced which accentuated this point, multiple times which immediate takeover by the safety driver prevented an incident or accident.

8. How confident did you feel about the automated vehicle system when the system was engaged?

The routes required a varying degree of alertness, for areas and situations which had high likelihood of disengagement, as well as those which were consistently uneventful. This was learned over time, and shifted with some of the adjustments applied over the course of the project.

9. Were there any limitations to the HD maps?

The behavior of the system was locked to the map and couldn't be changed due to the limitations of the hardware and software. Relaying changes to the maps and getting them applied was a time-consuming process.
Pre-programmed speed limits and locations need to be able to have direct override by the deployment team. It was also difficult to prepare to plan a route in Dreamview if we were not close enough to the route, because the boundaries of the map were limited. Sometimes there was too much data for the entire route to be loaded and visible.

10. Comments on the three routes:

    a. Selection method.

The deployment team primarily came onboard after the selection had been made, and was responsible for executing the deployment more so than selecting it. Given the experience in deployment, the team would be excellent consultants in selecting new areas to pursue future for future deployments, to compare and contrast with the data already collected, as well as to offer insight into the potential limitations of said routes.

    b. HD map data collection and processing.

Some map data collection was performed to engage the Fusion with the Autoware autonomous system. A high degree of precision on the route, as well as demonstrating the limitations through repeatability, seemed necessary. Having reliable localization signal through GPS and cellular corrections was also critical, and not always a given for certain rural areas with limited service and geographical features being impactful as well.

    c. Were there particular route segments where disengagements occurred regularly?

Yes, especially for particular types of disengagements, like the localization dropouts due to low GPS and/or cellular signal corrections, or downtown Athens which had a large number of vehicle and pedestrians, and intersections for their individual complexities and relative traffic behaviors.

    d. How quickly did you learn the types of road conditions (curves, etc.) would be best not to engage?
    e. How would you describe the differences between routes and how the vehicle handled those differently?
    f. What roadway features were:
        i. Missing?

An additional route closer to TRC in Bellefontaine/Marysville would be very helpful to test changes done in the vans, Athens being the only option to test on public roads. There are areas especially near the ski resort in Bellefontaine which could mimic the conditions experienced in the foothills of Appalachia where Athens is situated, even the TRC off-property course could be potentially leveraged for at least terrain if not traffic conditions.

ii. Challenging?

For autonomous mode, intersections were always the most challenging, regardless of layout, but especially for the ones which included any type of slope – both upward and downward.

iii. Useful?

iv. Variety/Design types?

There was a stretch on the blue route which was rural, and narrow. There were no lane markings. Any oncoming traffic warranted disengagement.

11. Were there unique challenges for automated vehicle technology (while in automated mode) operating on rural roads?

Rural roads are more likely to be outside of cellular service range, and can result in lower levels of localization, so location was known to a lesser degree and that caused travel outside of the intended lane.

12. Were you able to travel at a speed you were comfortable with?

Speed of travel is one thing that definitely could use more direct input from the deployment team. Locations and set speeds were determined by the map, and in many cases the extent of reduced speed limit as recommended for curves and highway ramps did not align with the general flow of traffic, so many disengagements were merely to directly control speed due to surrounding vehicles.

13. What was your opinion about the overall comfort level of the vehicle in automated versus manual mode?

Automated mode took some getting used to for an acceptable degree of comfort. This was achieved both through the course of CE testing in 4-5 days or about 40 hours and attuned to each route once reaching full deployment. Once it was better understood how the system reacted, it was more comfortable gauging when to remain engaged versus disengaging to resume full control in manual mode.

a. How do you think a passenger might have felt regarding comfort level?

There were several project members (who weren't drivers or operators) who rode as passengers, and not many opted to repeat the experience. With some acclimation as well as the aforementioned adjustments to the system behavior from the input of those who participated in deployment, the passenger experience could be improved for a wider range of personal levels of tolerance. A key difference would be participating in the ride exclusively, rather than having to monitor multiple points of technology, which can be difficult at times in the hilly, curvy areas even for those who don't easily get motion sickness.

14. Did you observe any situations in which the vehicle could not detect an object near or in the roadway?

a. Did you have to intervene in those cases?

Intervention was always taken in the cases which the object was too close to the known programmed path, or in which the object was likely to travel in a direction at a speed likely to intersect or come close to intersecting the vehicle's path of travel.

15. What are your overall thoughts on operating the passenger vehicles with automated vehicle technology while in automated mode?

a. What are your thoughts/conclusions of operation on the rural portions of the three routes?

Having consistent data/GPS connection in rural areas is a critical area of concern for reliable operation autonomously.
Adjustments in the map for both longitudinal speed as well as latitudinal placement relative to the lane need to be made with consideration for actual traffic behaviors, as well as specific local features, like cresting a hill with a sharp incline change, intersection layouts, surrounding traffic (both moving and parked), and pedestrian pathways including not just the legal ones but also the likely/occasional ones

16. Given the field deployment experience, what future research questions and field deployment activities would you suggest?

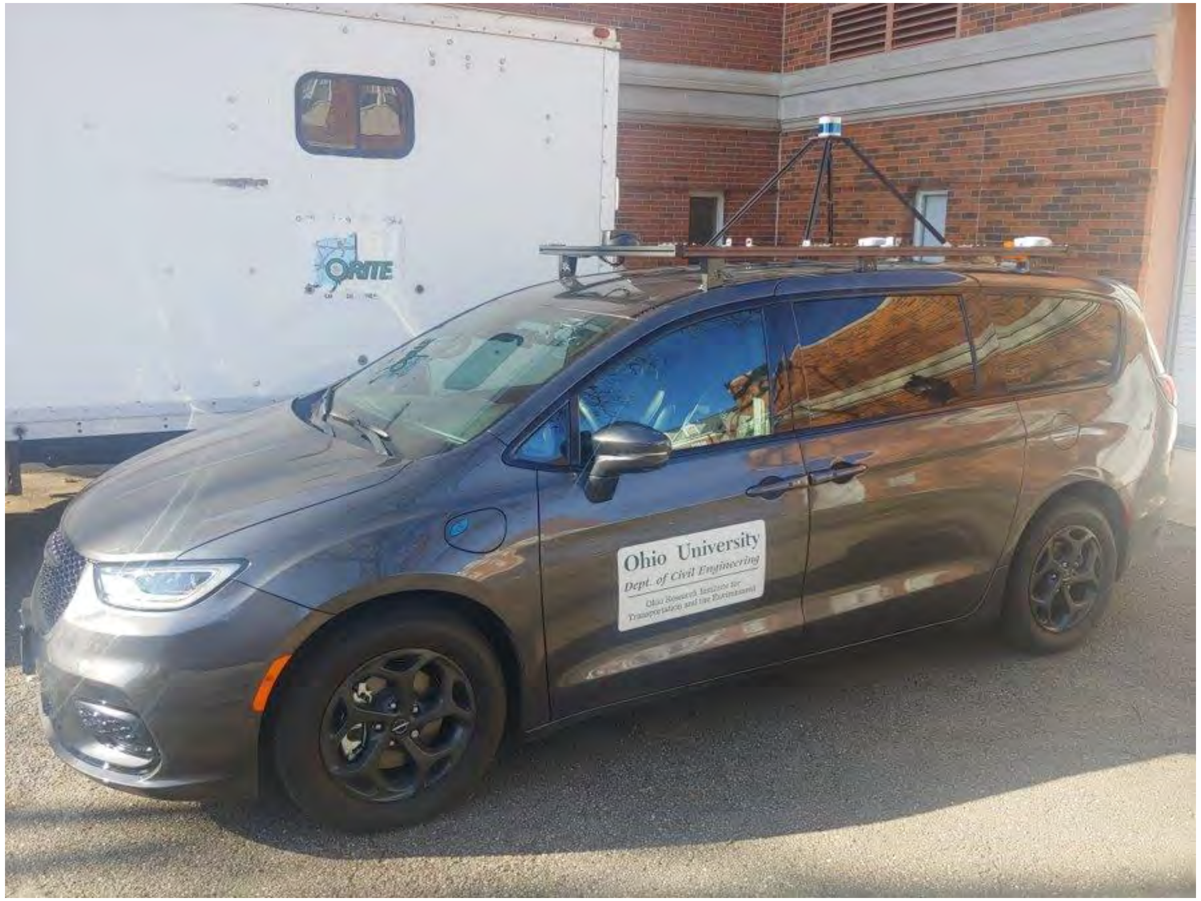
- Comparison of existing and new technologies/stacks/systems limitations under rural conditions such as the turns and hills and types of traffic experienced, narrow unmarked roads
- How the range of existing technologies interact collectively with each other
- People's behaviors (behavior changes) when knowingly versus unknowingly encountering autonomous vehicles (both pedestrians and other drivers)

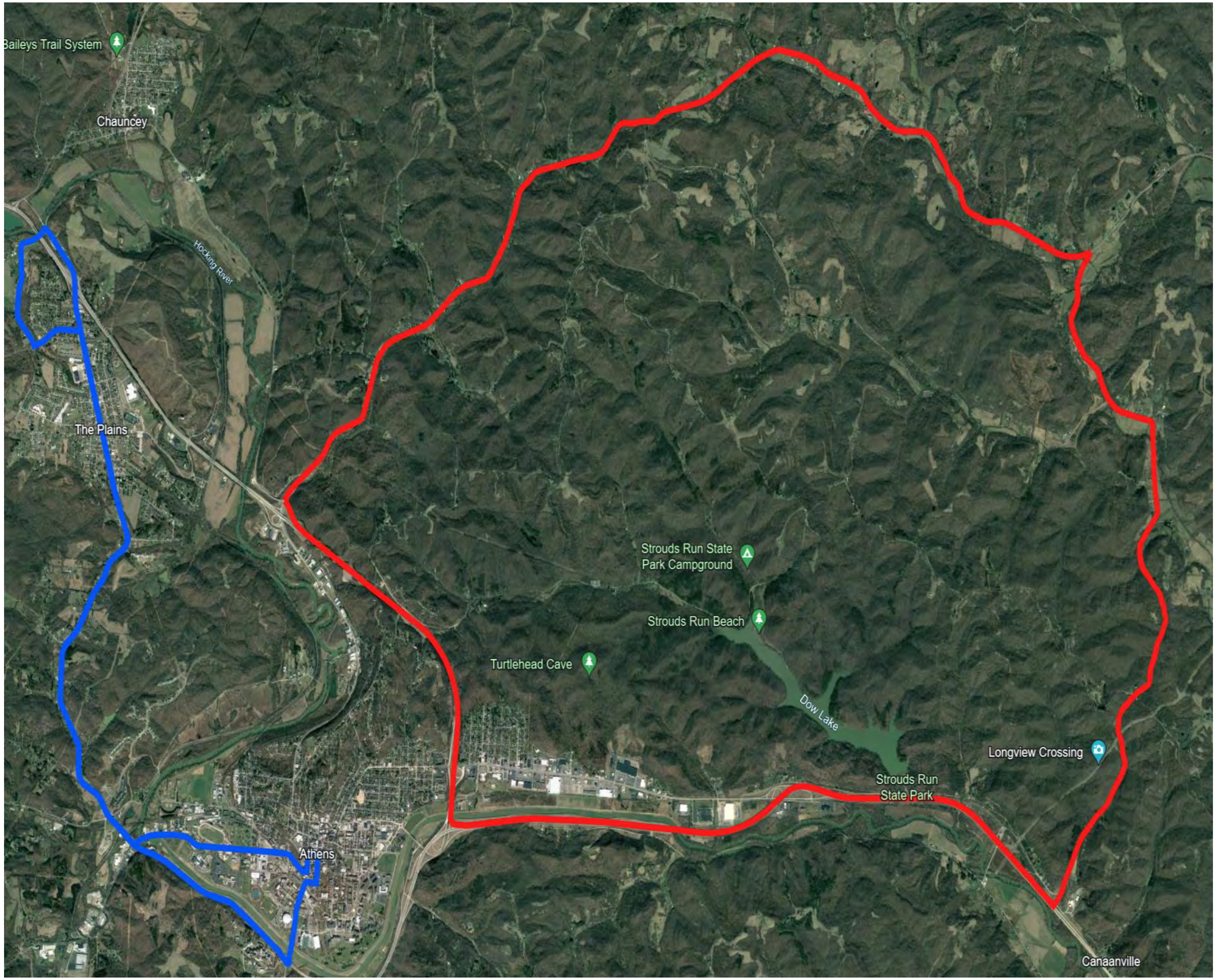
Appendix B9
OU ADS Project Deployment Focus Group Questions

Ohio Rural ADS Project
Deployment Focus Group Questions

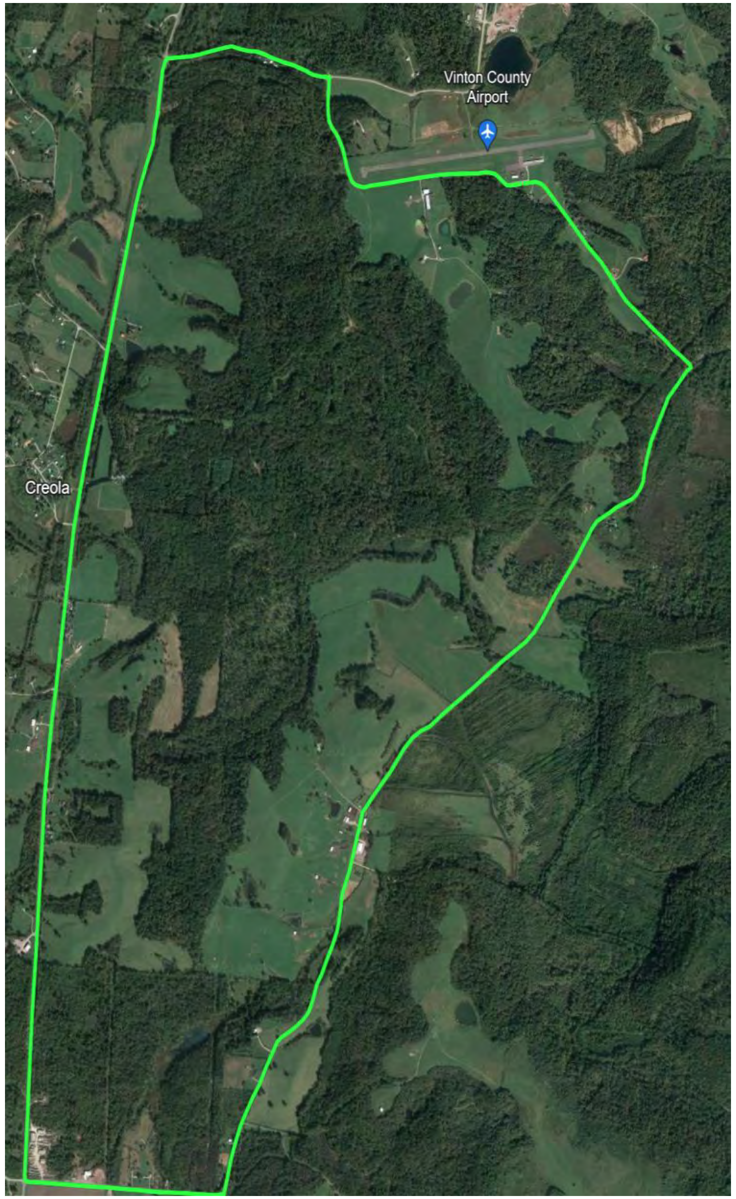
Moleski, Roback, Wilhelm

02/16/2024





Baileys Trail System
Chauncey
Hocking River
The Plains
Athens
Strouds Run State
Park Campground
Strouds Run Beach
Turtlehead Cave
Dow Lake
Longview Crossing
Strouds Run
State Park
Canaanville



Vinton County
Airport
Creola

What is your general impression of the automated vehicle technology used on the three Athens routes while in automated mode?

a. What features were useful?
    a. Travis:
        - Easy to manually take over, when necessary (gas/brake/steering/button)
b. What features were not useful?
    a. Travis:
        - None that come to mind, but could use better debugging when system fails to engage.
c. How easy was it to engage the system?
    a. Travis:
        - Easy to engage, identical to cruise control
        - Feels like cruise control in current state
d. What were the general limitations of the technology?
    a. Travis:
        - Trajectory predictions, stop light detection
e. What were the technology operating challenges?
    a. Travis:
        - GNSS-constrained navigation
f. What were the roadway challenges?
    a. Travis:
        - Highway/dual lane operation (Red route).
            a. Cars often predicted to pull in front of vehicle while passing.
        - Green route: Stop sign turning on to highway
        - Blue route: Roundabout

What are your thoughts on other drivers' behavior around the automated vehicle while in automated mode?

- Travis:
  1. Generally treated as a normal vehicle. Several instances of cutting vehicle off, getting between main and safety vehicle, and tailgating

- Cameron:
  1. Normally no different than manual driving but slow speed limits on certain roads will sometimes cause a line of cars behind us which can lead to frustration. Early stopping and late takeoff from stop signs and lights can be confusing for other divers.

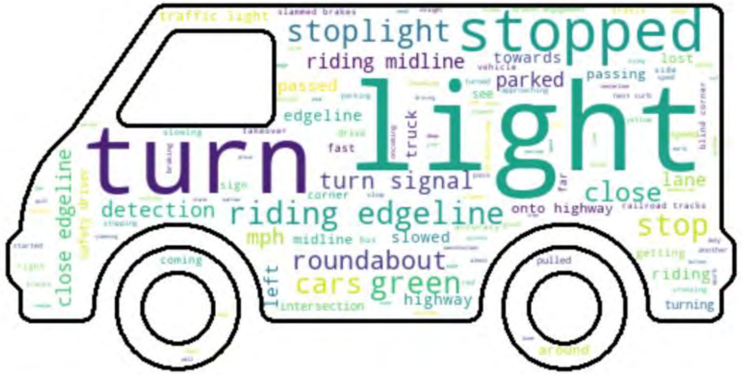
- How is this different on rural roads versus urban/suburban roads?
  1. Travis:
     - People more likely to pass in rural areas.
       - Regardless of lane marking... (double yellow most frequent to pass)
     - People more cautious in urban
  2. Cameron:
     - Rural roads often have larger build up of vehicles since the curvy nature of the roads require autonomy to be tested at slower speeds.
     - Urban sees more frequent stops but the van drives closer to the speed limit

Were there changes in automated mode performance between the test track/private road and public roads?

- Travis: (Ridges)
  - Not necessarily, our main testing track did not include many pedestrians, stop-signs, or stop lights.

- Cameron:
  - For the most part it feels the same after the maps were updated. In ideal conditions the autonomy feels very similar between test track and public roads.

What were the operating challenges with the vehicles used in the field deployment?

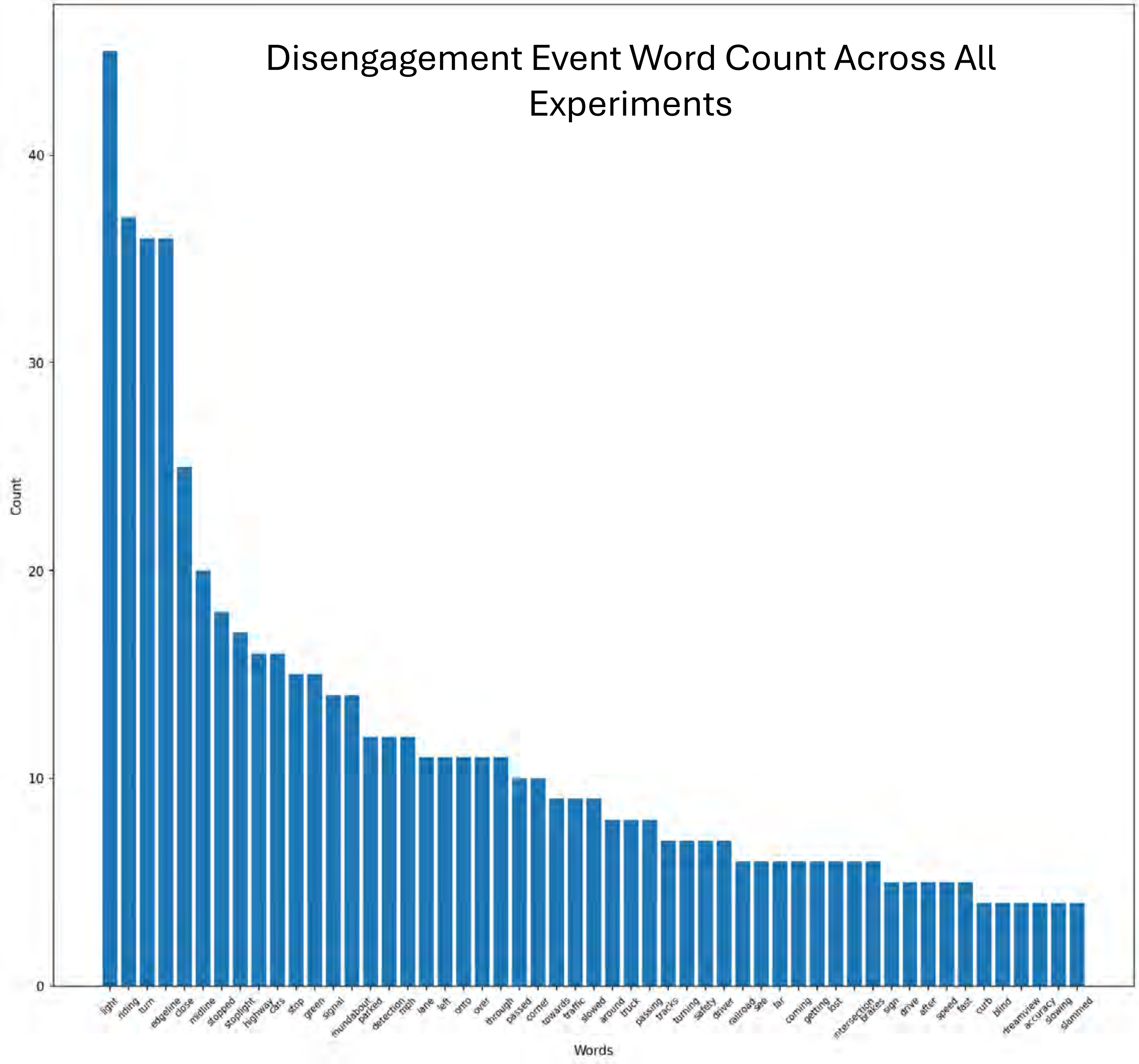


a. What were the challenges with the technology in automated mode?
   - Travis:
     - Trajectory prediction
     - Stop light detection
     - GNSS-constrained navigation (forests/canyons/overpass)
     - Roundabouts

b. What was the most prevalent type of disengagement the system experienced?
   - See diagram of comments
   - Following slides

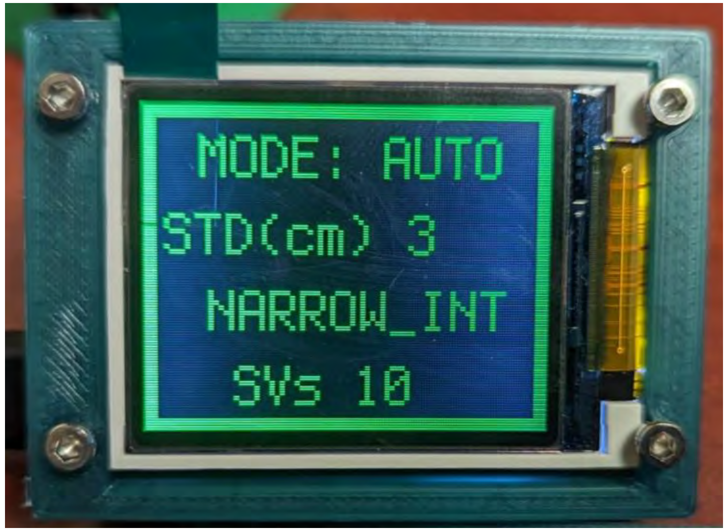
c. How often did you have to disengage the system manually?
   - **Green route: 11 runs, 39 takeovers, <u>3.55 average per</u>**
   - **Red route: 9 runs, 71 takeovers, <u>7.89 average per</u>**
   - **Blue: 16 runs, 152 takeovers, <u>9.50 average per</u>**

d. What were the most common reasons for a disengagement?
   - See diagram of comments
   - More on following slides


Disengagement Event Word Count Across All Experiments
Count
0
10
20
30
40
Words
light
riding
turn
edgeline
close
midline
stopped
stoplight
highway
cars
stop
green
signal
roundabout
parked
detection
high
lane
left
onto
over
through
passed
corner
towards
traffic
slowed
around
truck
passing
tracks
turning
safety
driver
railroad
see
far
coming
getting
lost
intersection
brakes
sign
drive
after
speed
fast
curb
blind
dreamview
accuracy
slowing
slammed

Are there any missing features in the automated vehicle technology while in automated mode?

- Travis:
  - o Visual/verbal readout to driver on state of autonomy
    - Localization accuracy, traffic light detection,
      - We developed our own visual solution
    - Driver currently has no feedback on system state
  - o Improved localization in constrained environments
    - Feature based, SLAM, etc.
  - o Debugging necessary
    - It is hard to trust a system when I don't know how it is breaking.



What are your thoughts on the reliability and consistency of the automated vehicle technology while in automated mode?

a. How reliable was the system when starting?
   - Travis:
     - Not very. We would often have to return to a parking lot to debug system.
     - After takeover, sometimes would slam on breaks when re-engaging.
   - Cameron:
     - Often has issues at the start when doing blue route because we attempt to engage autonomy very fast after setting up the system
     - Red and green routes often work well when initially engaging in autonomy because it takes longer to reach the route.

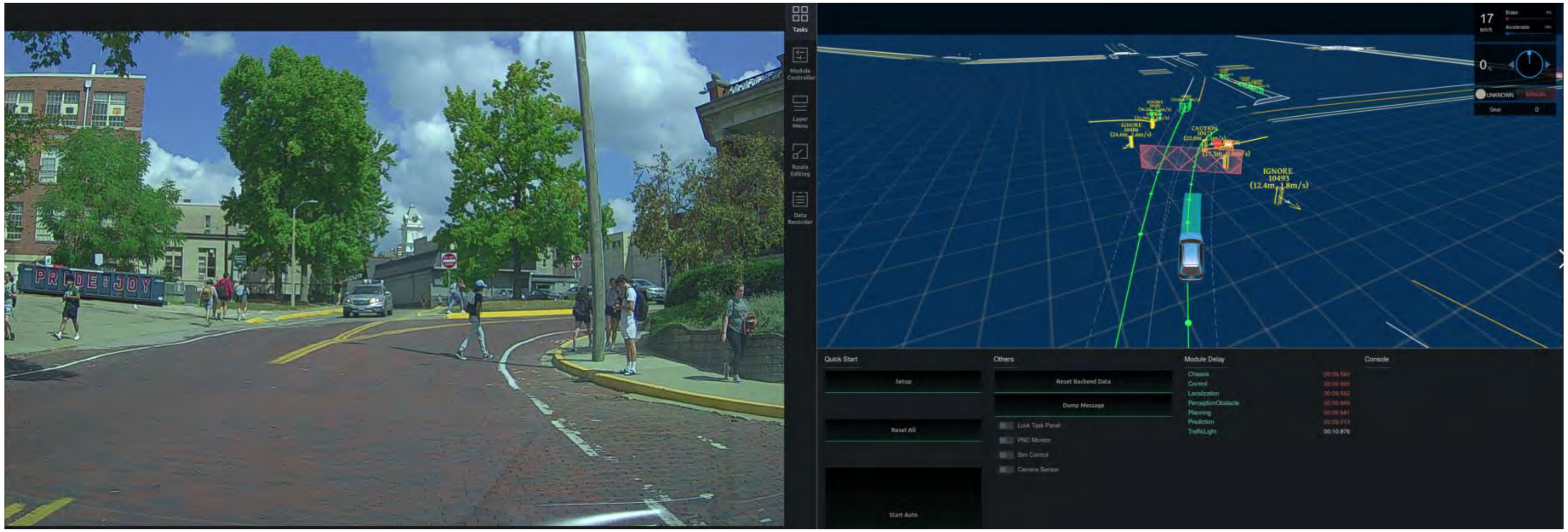
b. How easy was it to engage the system?
   - Travis:
     - From a driver perspective, very easy. Single button press
     - From an Apollo perspective, requires knowledge of:
       - Unix, Docker, sub-pub messaging, navigation, LiDAR, camera, etc to verify system operating correctly
         - **Trust of system is lacking**
       - If something breaks, expertise is required to debug.

What are your thoughts/conclusions on driver attentiveness while in automated vehicle mode?

- Travis:
  - A driver that knows how the system works, is going to be able to predict how/when it breaks:
    - E.g:
      - Forests, urban canyon, GNSS-constrained = navigation problems
        - Getting close to road lanes because of large position error
  - Boils down to trust of system.
    - I was very much more attentive operating this system than on average in my own vehicle
    - Green route was more lax. Less takeovers
    - Blue route was stressful. Most takeovers
  - **The more success we have had on a route in autonomy the more comfortable I am, resulting in being less attentive.**
- Cameron:
  - Most stressful in high traffic/pedestrian environments where van movements have to be precise so the driver has to be more attentive
  - Can often identify when the van is having problems but cannot always predict the movements of vehicles around us

How confident did you feel about the automated vehicle system when the system was engaged?

- Travis:
  - o Route and traffic dependent:
    - Empty roads with no traffic lights or roundabouts (Green Route)? Very confident
    - Blue route (downtown, many traffic lights, roundabouts. Not very.
- Cameron:
  - o Moving at high speeds in areas with poor accuracy was questionable
  - o Low speed areas with no traffic were often very confident and required few takeovers



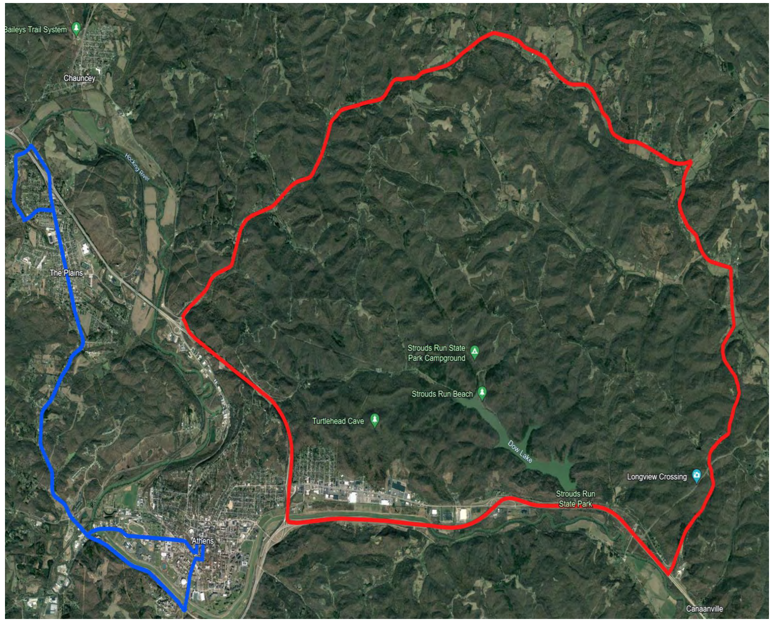
Were there any limitations to the HD maps?

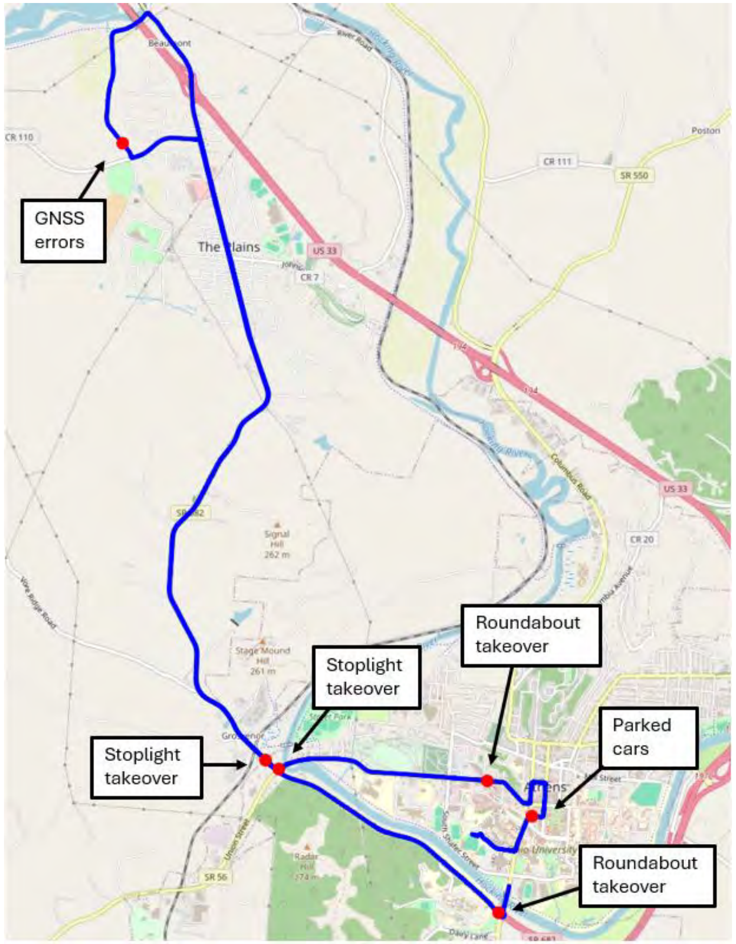
- Travis:
  - Requiring pre-mapping:
    - If an issue was identified while testing, would have to send back to company to re-map:
      - E.g: Speed limits, lane markings, train-tracks being treated as stop-light

- Cameron:
  - Some turns felt like the van was swinging too wide
    - Urban roads with cars parked around corners sometimes caused takeovers

Comments on the three routes:

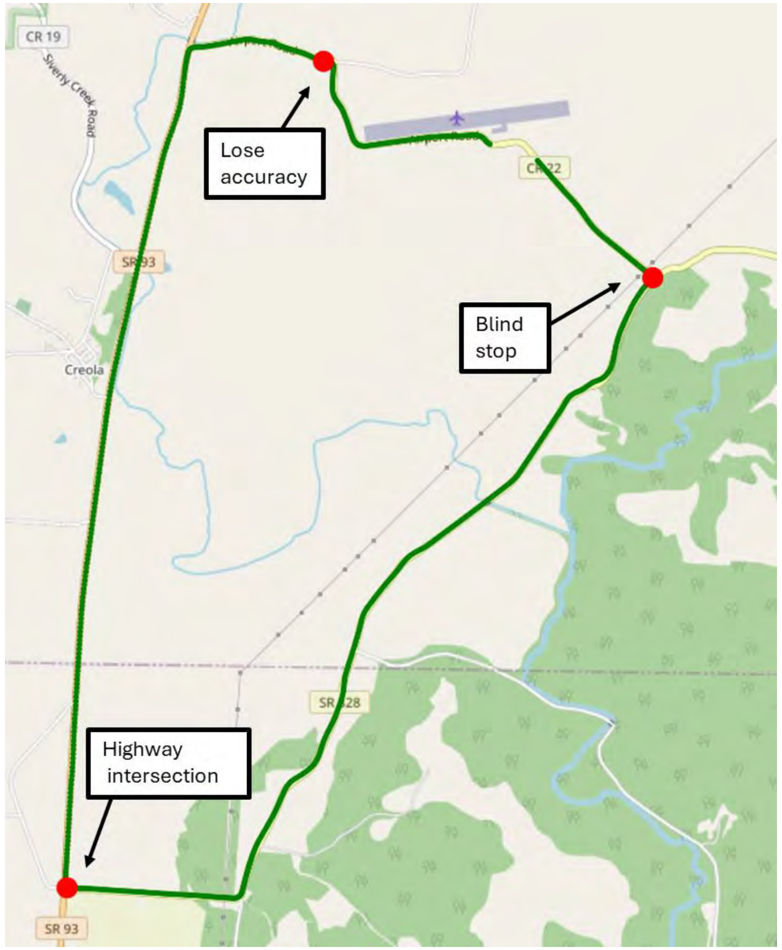
- Selection method.
  - Not sure. Chosen by Dr. Wilhelm and other planners
- HD map data collection and processing.
  - Collection and processing done by Mandlii
- Were there particular route segments where disengagements occurred regularly?
  - **Yes, see figures on following slides**
- How quickly did you learn the types of road conditions (curves, etc.) would be best not to engage?
  - Travis:
    - Very: If a problem occurred once, I would not be comfortable to re-engage in the future, until I know why it failed
    - 1 or 2 tries.
- How would you describe the differences between routes and how the vehicle handled those differently?
  - Travis:
    - Urban/sub (blue), suburban/rural(green), highway rural/sub (red)
    - Urban: Trust, pedestrians, traffic lights
    - Suburban/rural: Navigation and lane keeping
    - Combo: Traffic
- What roadway features were:
  - Missing?
    - Mapping of pedestrian crossings
  - Challenging?
    - Highways, roundabouts,
    - Stop signs
  - Useful?
  - Variety/Design types?



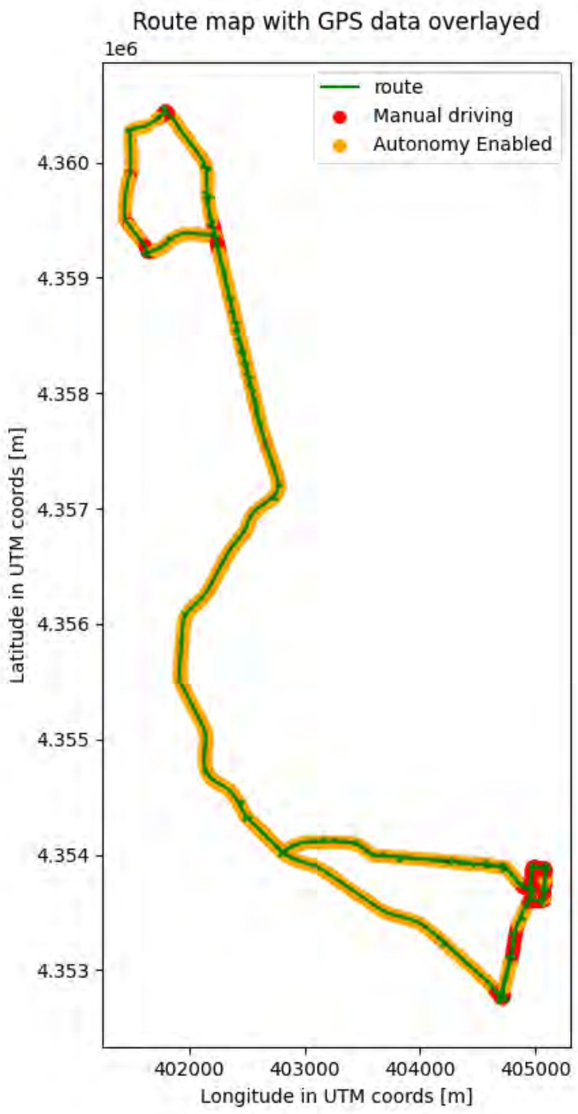


Blue

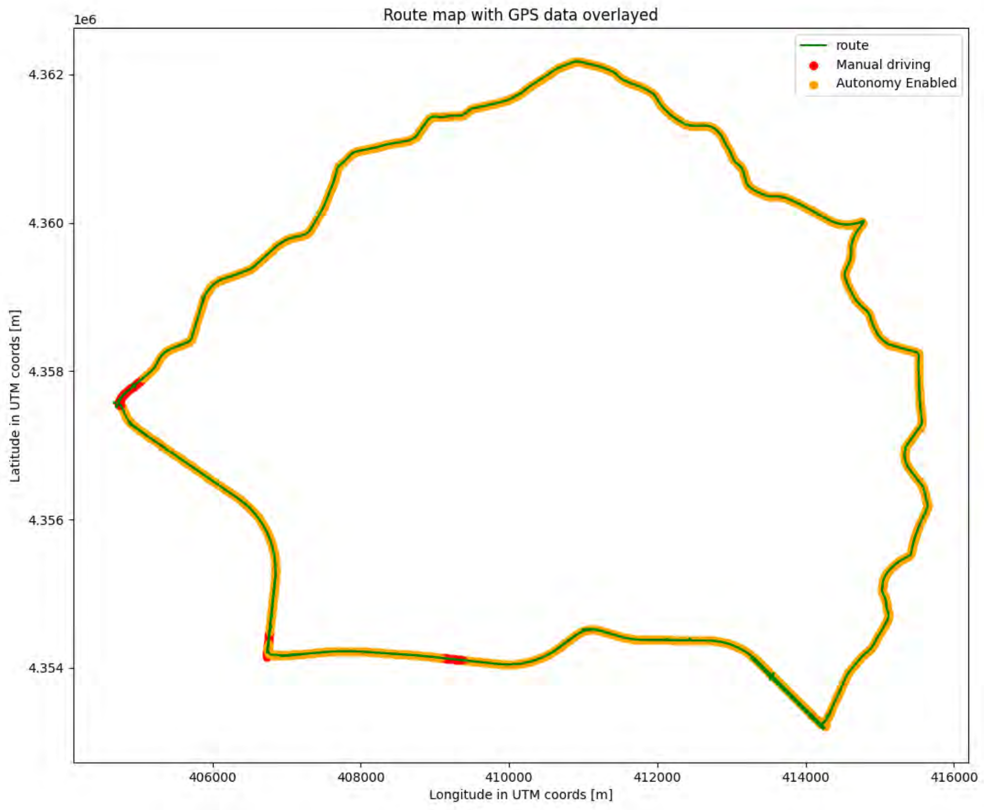
Red



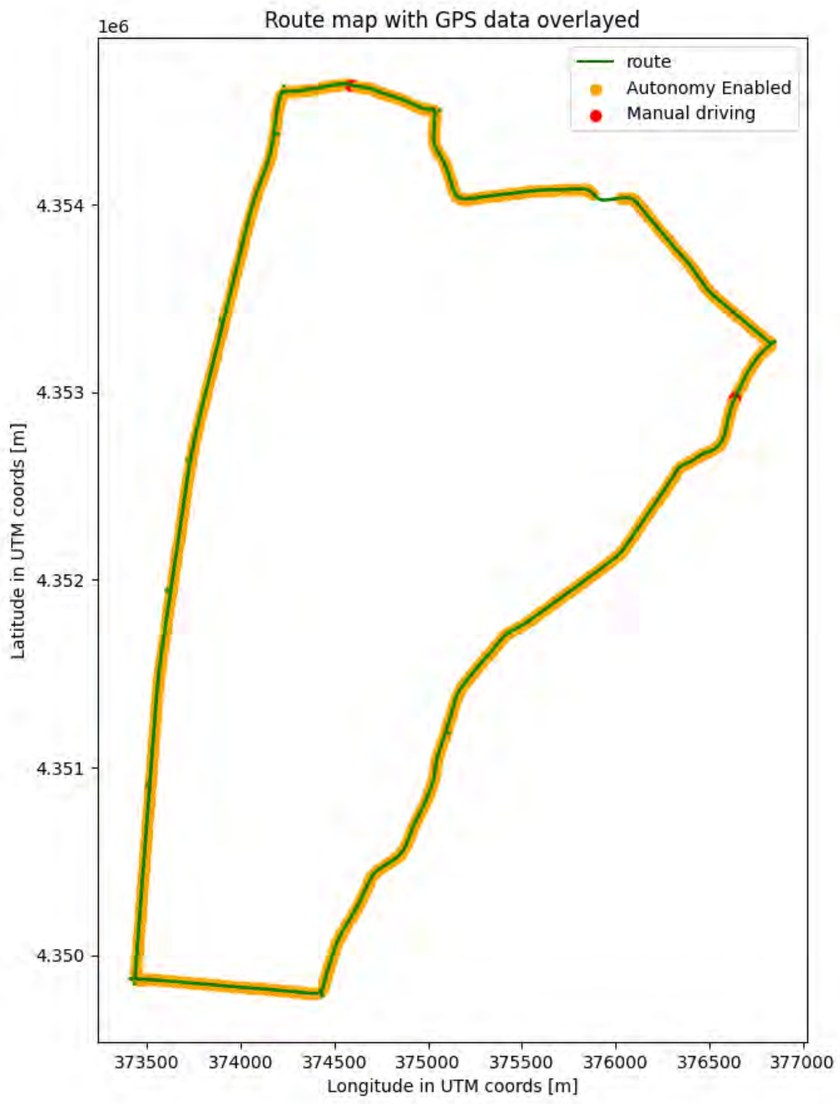
Green



Blue



Red



Green

Were there unique challenges for automated vehicle technology (while in automated mode) operating on rural roads?

- Travis:
  - Speeding, other vehicles
  - Navigation: Loss of SVs, corrections (cell service), or Terrastar corrections
  - Generally trusted more than urban roads:
    - **Less driver/pedestrian intent to predict**

- Cameron:
  - Blind corners at stops did not let the van detect oncoming traffic
  - Sharp turns in areas with high-speed limits would cause the van to slow down prematurely

Were you able to travel at a speed you were comfortable with?

- Travis:
  - Populated areas would generally be too fast
    - Downtown/Court Street
    - Speed limit is fine if empty, but with crowd was too fast
  - Generally yes, but other drivers on the road? Not so much.

- Cameron:
  - Some curvy portions of the rural roads felt too fast while others felt slow. All can be fixed with updated maps but for the most part there are no problems with the speed
  - The more times we drove a route the more comfortable I would feel at higher speeds

What was your opinion about the overall comfort level of the vehicle in automated versus manual mode?

- How do you think a passenger might have felt regarding comfort level?
  - Cameron:
    - Comfortable with both in low speed and traffic environments. High speed in autonomy is less comfortable as passenger because you have no control of the takeover if needed.
    - Knowledge of the system helps making the ride more comfortable because you can predict when a takeover should happen.
- Driver:
  - Travis:
    - Route dependent: More comfortable in automated on Green route (rural). More comfortable in manual on Blue (urban)

Did you observe any situations in which the vehicle could not detect an object near or in the roadway?

- Travis:
  - Traffic work
  - One instance on green-route when merging, did not detect oncoming Toyota Tundra
  - I think the object detection network is trained for cars/people
    - Trash cans on blue route sometimes an issue
  - Parked cars often an issue on Blue

- Cameron:
  - Occasionally the van feels like it takes too long to detect objects we are driving up on which either leads to a takeover or aggressive last second braking

What are your overall thoughts on operating the passenger vehicles with automated vehicle technology while in automated mode?

- Overall:
  - Travis:
    - Route/environment dependent. When lacking a measure of intent in heavy traffic, I have very little trust the system will be safe. The more I learned about how the software worked, the more I was comfortable with the system.
  - Cameron:
    - In areas with low traffic and high localization accuracy the vehicle feels like it can be very successful. Need a way to keep consistent accuracy or the van starts to move out of lane which cannot happen. Heavy traffic areas somewhat depend on other drivers which is an issue.
- What are your thoughts/conclusions of operation on the rural portions of the three routes?
  - Travis:
    - I was generally more comfortable in the rural areas because the main issue was navigation.
      - Less dangerous if something goes wrong and we know generally where our solution degrades
  - Cameron:
    - At low speeds I was most comfortable on the rural portions but loss of accuracy at high speeds felt like it could be dangerous. Even though the other drivers on rural routes would try to pass us they did not feel like they presented much danger to the vehicle.

Given the field deployment experience, what future research questions and field deployment activities would you suggest?

- Travis:
  - Improved navigation techniques in constrained environments
  - How do we measure intent of other drivers/people from an autonomy standpoint?
    - Should help with roundabouts and traffic lights
  - Easy to modify/fix mapping.
    - Speed limits, corner fixes
  - Improvements to traffic light detection and mapping
  - Less aggressive braking
    - From Jay Wilhelm “Angry teenager”
  - Steering wheel turning when stopped fix
    - PID integrator windup?

Appendix B10
OU Human Factors Experiment Setup and Process

Human Factors Experiment Setup and Process

Jay Wilhelm, Ph.D.
Cameron Roback
Ohio University IDEAS Lab

Introduction

OHIO was tasked with performing human factors measurements to identify driver attention during disengagements while controlling an autonomous vehicle. Driver visual focus might provide insight into challenges faced during autonomous operation. Tracking disengagements helped identify limitations of the current technology such as poor object detection and vehicle deviation from the specified route. Knowledge of limitations was crucial in assisting researchers with the development of ground-based autonomous vehicles. Disengagement data was collected and analyzed to determine the most common reasons for disengagement based on the location of driver gaze. The following document shares the experiment setup and methods for processing data.

Equipment

Data was collected using a passenger-controlled comment system and eye tracking glasses worn by the driver. Comment creation used a python script for recording descriptions of each disengagement coupled with a GPS receiver to determine exact location and epoch timestamp. GPS tracking enabled multiple experiments to be compared, allowing locations with repeated takeovers to be identified. Eye tracking was performed using Tobii Pro Glasses 3 equipped with cameras integrated in the lenses for pupil tracking and an outward facing camera to record the driver point of view. Pupil tracking allowed driver gaze location to be identified relative to the video frames of the outward recording. Gaze was overlayed on each video using Tobii's Glasses 3 software. Recordings were analyzed five seconds before and after disengaging to determine the cause along with where driver focus shifted immediately after takeover. Analysis of the recordings showed disengagements were normally caused by what the driver was focused on, but also helped identify when the van would unexpectedly stop or turn the steering wheel leading to a disengagement. Equipment components and visual representations are provided below for reference.

U-blox EVK-G26H components:

- Circuit board
- Power cable
- USB cable
- GPS antenna

Tobii Pro Glasses 3 Components:

- Recording unit
    - Battery
    - SD card
- Head unit
- Ethernet cable

Laptop:

- Python script for comment creation
- Tobii Glasses 3 application

Figure 1: U-blox GPS receiver and Tobii Pro Glasses 3.

<u>Setup and Data Collection</u>

Comment data included detailed descriptions of each disengagement, epoch time, and van coordinates. Comments from each drive were stored in a JSON file and used during processing to locate disengagement events in the eye tracking recordings. Setup of the comment collection system was completed as follows:

1. Secure GPS antenna to the top of the van and park outside
2. Power the u-blox GPS receiver and connect to the laptop via USB
3. Select the COM port used for data transmission and specify what route was being driven in the python script
4. Verify satellite data has converged by starting the script and checking that the output on the computer terminal provides GPS coordinates as seen in Figure 2

```
$GPGGA,182837.00,3919.57777,N,08206.40494,W,1,04,4.50,203.3,M,-33.6,M,,*63
$GPGGA,182838.00,3919.57761,N,08206.40515,W,1,04,4.50,203.1,M,-33.6,M,,*61
$GPGGA,182839.00,3919.57746,N,08206.40542,W,1,04,4.50,203.0,M,-33.6,M,,*66
$GPGGA,182837.00,3919.57717,N,08206.40597,W,1,04,4.50,202.8,M,-33.6,M,,*6D
$GPGGA,182838.00,3919.57697,N,08206.40642,W,1,04,4.51,202.5,M,-33.6,M,,*6C
```

Figure 2: Example of converged GPS output results.

Eye tracking data consisted of a video from the driver's perspective and 2D pixel coordinates describing where the driver was looking relative to each frame. Data was stored with the recording unit and pulled directly from the SD card during processing. The procedure for operating the Tobii eye tracking glasses is seen below:

1. Insert battery and SD card into recording unit and power it on
2. Attach wired connection from head unit to the recording unit
3. Connect recording unit to laptop via ethernet cable
4. Open the Glasses 3 software and select direct wired connection to access recording mode
5. Enter the name of the participant using the glasses and calibrate when they are correctly positioned on the driver's face

After the comment collection system and eye tracking glasses were set up, data collection could begin. Once autonomy was initiated, the steps for collecting data included:

1. Verify that proper GPS data is still being transmitted to the terminal
2. Start the eye tracking recording
3. During disengagement press the green button on screen to open a text box as seen in Figure 3
4. Insert description of disengagement and press enter to store in JSON file
5. At drive completion press stop recording to end the video and close the comment GUI to stop the script
6. Wait for the Glasses 3 application to verify that data has been saved and power off the recording unit

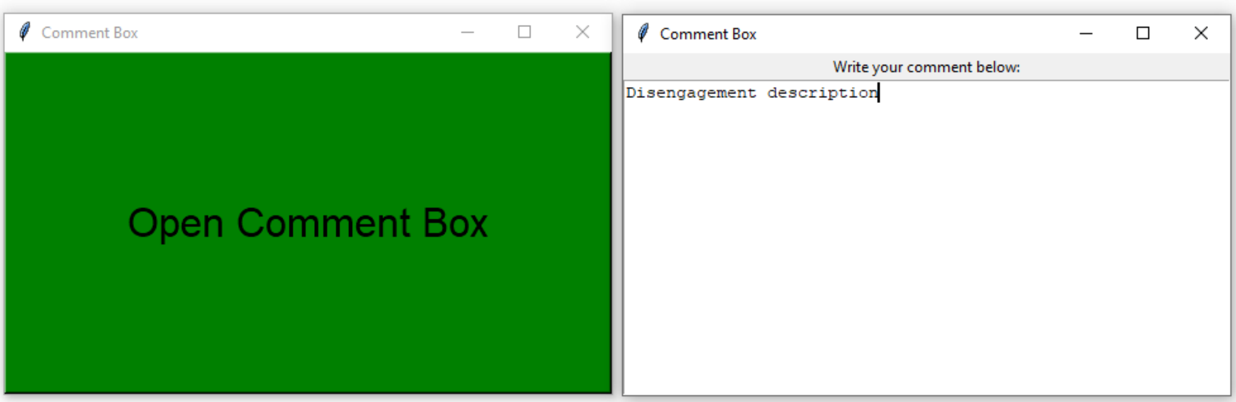


Figure 3: Comment box GUI from python script.

Processing data

Post processing began with importing each recording into the Tobii Pro Lab software. Disengagements were marked as events with assistance of GPS information from the JSON files. Identifying events in Tobii Pro Lab was necessary because they were included in exported gaze data and used to determine time regions of interest. Along with events, exported data from each project included UTC start date, UTC start time, and 2D gaze coordinates. A python script was used to determine if driver gaze in the Tobii recordings focused on any areas of interest (AOIs) during the disengagement events. The AOIs for this project included places the driver would commonly view such as out of the windshield, mirrors, the speedometer, and the infotainment system. For each disengagement, driver gaze from the recording was mapped to a still image which had AOIs marked. Figure 4(A) shows an image from a disengagement where the driver was focused on traffic at a roundabout with driver gaze identified using a green circle. Figure 4(B) shows the still image with green AOI boxes, and the mapped gaze point represented using a red circle. The still image selected was not from a specific disengagement but was chosen as a standard image that clearly displays all locations of interest for driver focus. Using the same standard image to map all disengagements provided consistency in the mapped results. Mapping was done using the scale-invariant feature transform (SIFT) capabilities of the OpenCV package in python. SIFT converted the video frames and still image to grayscale and identified similar keypoints between them to match common features. After matching keypoints, a homography matrix was created which identified what transformations there were between matched keypoints in the two images. Identifying the transformations allowed the program to determine how the recording frame was shifted relative to the still image so the known gaze point could correctly be mapped. Using the mapped gaze point on the still image, the script tracked each frame from the disengagement events to determine if driver gaze was within an AOI and stored that result in a TSV file. After the SIFT operation was complete, another script was run which used YOLO for object detection on all frames the driver was determined to be looking out of the windshield. Object detection was done to identify if there was a specific obstacle that the driver was viewing, such as another vehicle or a person in the road, which caused a disengagement. Object detection results were stored in a separate TSV file and both were used to create plots which show driver focus during an experiment. The steps completed for full data processing were as follows:

1. Open Tobii Pro Lab and create a project using the recording data stored on the SD card
2. Open the comments JSON file and find location/time of each disengagement
3. Mark each disengagement using the event option in Tobii Pro Lab
4. Use the export data tab and select the required data needed to run the python scripts
5. Export the data to a TSV file using the time scale of milliseconds
6. Save an image from the recording video that clearly shows each of the AOIs
7. Insert the exported data file names into the python script
8. Adjust the date and run number to fit the experiment of interest
9. Run the script and draw the desired AOIs to the screen

10. View output data and plots to ensure that the program worked as expected

A)

B)

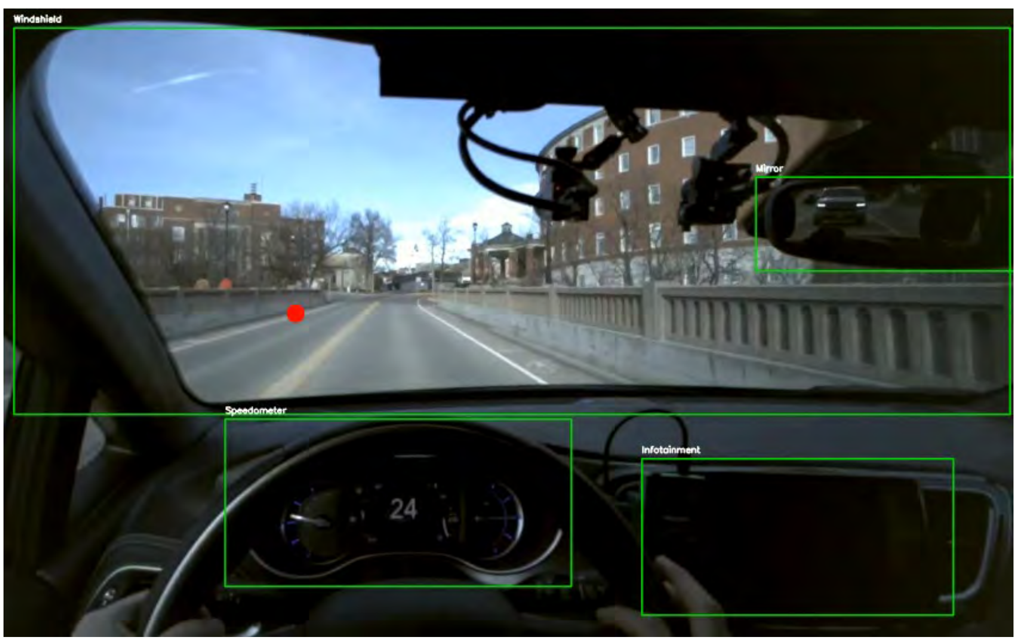
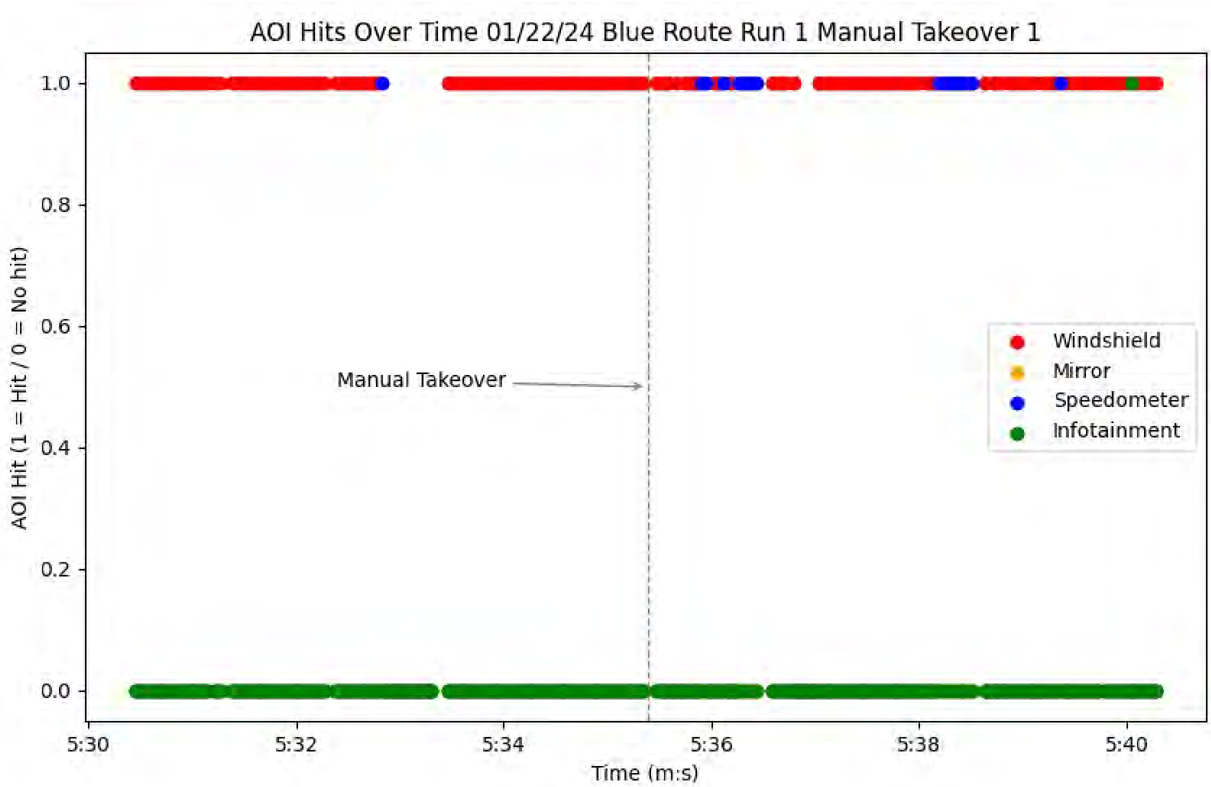


Figure 4: A) Original recording with gaze point displayed in green. B) Still image with marked AOIs and mapped gaze point in red.

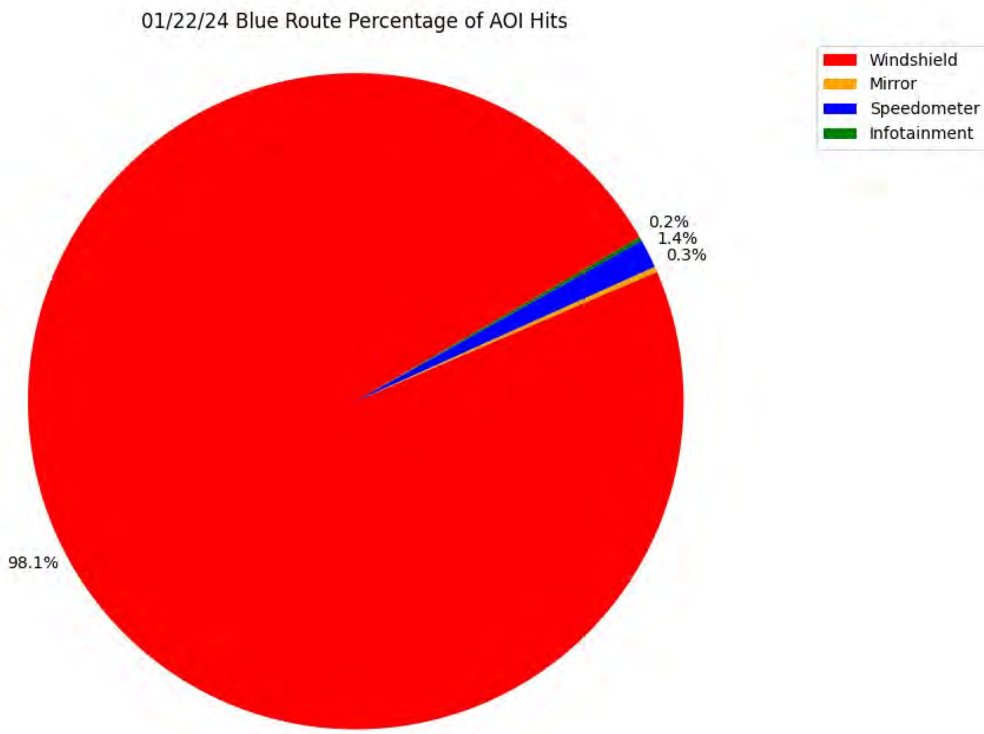
Current Results

Human factors measurements provided information about driver focus during times of interest around disengagements. Current results include the number of times each AOI was visited along with timestamps of each hit as shown in the examples from Figure 5. Recordings made with the Tobii glasses are 25 frames per second, so the hits recorded in each experiment are every 40 milliseconds. Figure 5(A) shows a single disengagement event with each point representing a hit or no hit at a specific timestamp. Manual takeovers were marked to show where the driver was focused at the exact time disengagement occurred. The addition of YOLO object detection was used to help identify in more detail what caused the driver to disengage since the windshield was the most common AOI hit. Object detection helped determine that the driver spent most of the disengagement event time looking evenly at other vehicles on the roadway and the environment around them as seen in Figure 5(D) with an example of object detection visible in Figure 6.

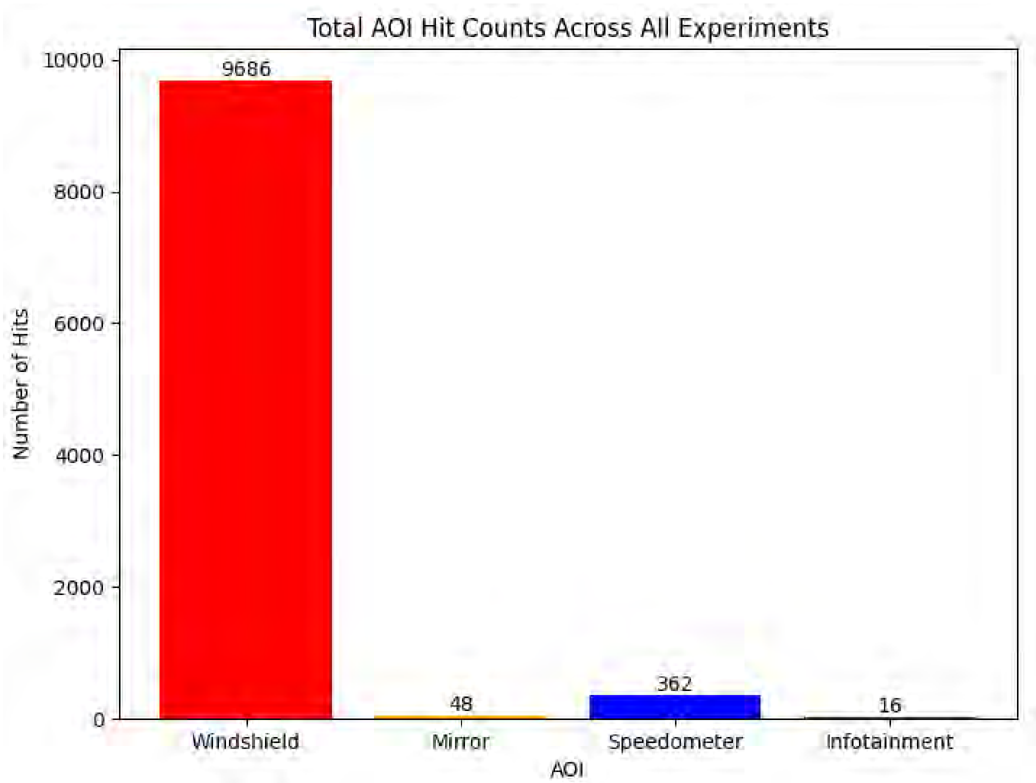
A)



B)


01/22/24 Blue Route Percentage of AOI Hits
Windshield
Mirror
Speedometer
Infotainment
0.2%
1.4%
0.3%
98.1%

C)


Total AOI Hit Counts Across All Experiments
10000
8000
6000
4000
2000
0
Number of Hits
9686
48
362
16
Windshield
Mirror
Speedometer
Infotainment
AOI

D)

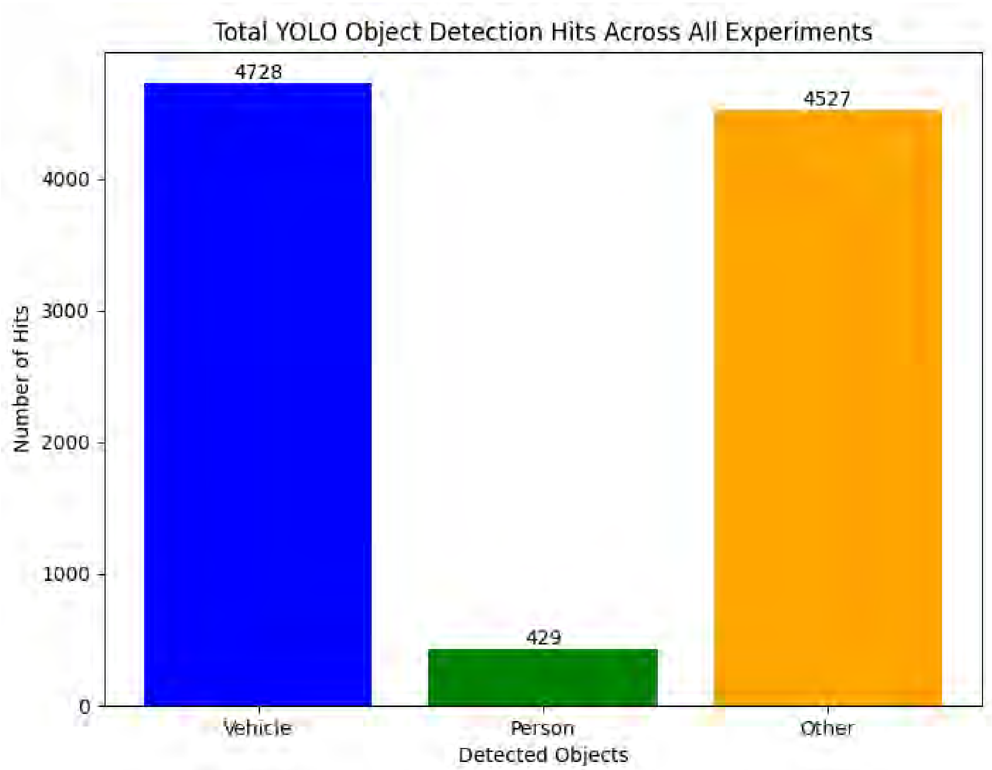


Figure 5: A) AOI hits per disengagement. B) Percentage of hits to each AOI for a full route. C) Total recorded hits in each AOI between all runs. D) Total recorded hits out of windshield with YOLO object detection.

The split showed that other vehicles were just as often the reason for disengagement as the van's ability to stay on the route. Disengagements caused by the actions of other drivers are important to recognize as potential hazards when moving forward with the development of autonomous vehicles. Hazards can include sudden changes in the environment such as a vehicle pulling in front of the van when it should not, or stationary obstacles that would normally not be in the route such as a vehicle that is poorly parked. Tracking the disengagements using recording of the driver's point of view allowed us to recognize what the cause was and how well the van reacted. Gaze results also showed that the driver was highly attentive to their surroundings with most of the event time being used to scan the outside environment instead of focusing inside of the van. Changes needing to be made to the system such as map updates, speed corrections, and hardware upgrades were able to be identified through the results of this research which help to improve the overall autonomous driving experience.

Figure 6: YOLO video output.

Appendix C
Stakeholder Results Documents

Appendix C1
Automated Driving Systems (ADS) Communication & Outreach Plan

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Communication & Outreach Plan

Updated January 21, 2022

INTRODUCTION

BACKGROUND

The U.S. Department of Transportation (USDOT) awarded a $7.5 million Automated Driving Systems (ADS) Demonstration Grant to the DriveOhio-led team of government, academia, industry and Southeast Ohio community partners. Managed by the Federal Motor Carrier Safety Administration (FMCSA), the ADS demonstration will deploy and test the safe integration of automated trucks and passenger vehicles on Ohio's rural roads and highways. Automated driving systems may one day improve access to jobs, goods and healthcare, and potentially improve mobility and reduce isolation for rural residents. The Ohio demonstrations and the data that is collected may assist in achieving those long-term goals.

Transportation-challenged populations are present everywhere, but their transportation burden is magnified in rural areas. Lack of transit options, limited direct routes, long travel distances and uneven roads are some of the added hurdles posed in rural environments. As a microcosm of the U.S., ADS deployments in Ohio serve as the ideal test bed due to the state's four-season climate, multi-route lanes and a diverse landscape of level, rolling and mountainous terrain.

ADS data from rural environments and cooperative highway applications are crucial to evaluating safety and developing and informing rulemaking. Southeast Ohio will serve as the testbed for the nation in deploying and testing rural ADS solutions, providing information and documentation regarding end-user engagement, planning, design, implementation, data collection and operation of the various automated transportation components. This demonstration includes a robust outreach component to engage end-users and the community at large to meet ADS goals and objectives.

The ADS Communication & Outreach Plan outlines the users, stakeholders, messages, communication tools and outreach methods to successfully accomplish this demonstration.

OVERALL DEMONSTRATION GOALS

The goals of the ADS demonstration are to:

- Pilot the safe integration of ADS into the nation's rural, on-road transportation system
- Fund demonstrations that identify risks and opportunities, shape rulemaking priorities and remove barriers to the safe integration of ADS technologies
- Gather significant demonstration data gathering and share for optimal learning
- Create collaborative environments that harness the collective expertise, ingenuity and knowledge of multiple stakeholders
- Educate Ohio's citizens about these transportation innovations and highlight economic opportunities as automated technologies are developed and scaled

COMMUNICATION & OUTREACH PLAN

PURPOSE

This ADS Communication & Engagement Plan outlines a series of proactive steps to engage and inform potential end users, partners, stakeholders and the public. It summarizes a methodical, inclusive and transparent process designed to excite participants to the possibilities yet manage expectations, work through issues of concern and share lessons learned so that others may benefit.

GOALS

- Support the demonstration goal to create collaborative environments that harness the collective expertise, ingenuity and knowledge of multiple stakeholders
- Outline a clear strategy and process that engages partners, end users, stakeholders and the public as appropriate throughout the demonstration lifecycle
- Establish easy to understand communications that clearly explain what the demonstration is/isn't and manage public expectations about what is in it for them
- Solicit input from potential end users and community stakeholders to determine rural mobility challenges and needs
- Develop a dialogue with key community leaders and end users to ensure multiple interests are considered as the demonstration progresses

- Inform the public, community and local jurisdictions about the demonstration and findings and to provide feedback opportunities, as necessary

OBJECTIVES

- Communicate with partners comprehensively on a cadence of key demonstration milestones
- Communicate with stakeholders consistently regarding end user needs collection and findings, systems engineering progression and deployment milestones
- Communicate with the public (including media and other travelers sharing the road) immediately prior to and during major demonstration milestones
- Provide structured feedback opportunities through online surveys, stakeholder/public meetings and other mechanisms that may inform future policy on public outreach related to automated vehicles
- Notify grantor of communications lessons learned yearly over the life of the demonstration

AUDIENCES

To select the most effective communication and engagement methods, three types of target audiences have been identified.

- ***Partners (and ADS demonstration peer/technical agencies and associations).*** Includes grant sponsors; federal and state agencies; ADS peer groups and organizations; and for the short-term demonstration needs: trucking companies and related trade associations; logistic councils; autonomous vendors and the transportation industry.
- ***Stakeholders (community leaders, agencies and future end users).*** For ongoing updates and the longer-term vision of using improved mobility to meet local needs, stakeholders may include regional, state and local officials where the demonstrations will occur; safety officials and emergency responders; health agencies/institutions and organizations; educational institutions; community organizations; business community and advocates; civic groups and transportation advocates.
- ***Public (other road users and major media outlets).*** Traditional and digital media outlets that regularly communicate with the general population. Travelers who share the roadways and highways where these deployments take place.

The following table outlines each audience type, specific entities, their expected level of participation/role(s) and planned outreach approach. Some levels of engagement will overlap, including the collection of specific end user needs. Any additions will be reflected in future Communication & Outreach Plan updates.

AUDIENCE TYPE	ENTITIES	ROLE	OUTREACH*
Partners			
Federal agencies and grant sponsors	FMCSA and USDOT (FMCSA will keep USDOT informed)	Review and advise on ADS demonstration approach and findings, inform and influence policy, build ownership and excitement in demonstration outcomes, support peer learning	Regularly scheduled updates and work sessions, quarterly reporting, access to digital demonstration files
State project sponsors	ADS Project Executive Board *(Governor's Office, JobsOhio, Transportation Research Center [TRC], Ohio Department of Transportation [ODOT] and DriveOhio)*	Review information and status to keep informed and engaged, build ownership and excitement in demonstration outcomes	Quarterly reports
Demonstration lead and associated offices	DriveOhio, ODOT Central Office (Communications, Data Governance, DoIT, Highway Safety, Legal, Operations, Planning/ Freight, Transit), ODOT District 10, TRC	Provide input on development, implementation and communication of the ADS demonstration, review and advise on ADS findings, inform and influence policy, build ownership and excitement in demonstration outcomes	End user needs focus groups and/or briefings, solicitation of input at existing meetings
ADS peer groups and organizations	Buckeye Hills Regional Council, City of Athens, DriveOhio Alliance, Jobs Ohio, Ohio University, Ohio Southeast Economic Development, Smart Columbus, ODOT D10	Identify rural transportation challenges and end user needs, provide support and feedback, build ownership and excitement in demonstration outcomes	End user needs focus groups and/or briefings, solicitation of input at existing meetings
Grant partners	American Honda Motor Company, Athens County Commissioners, AutonomusStuff, Bosch, Buckeye Hills Regional Council, Campbell's Market (McArthur), City of Athens, City of Marysville, Columbus Yellow Cab, Eastgate Regional Council of Governments, Foundation for Appalachian Ohio, Greater Ohio Policy Center, Jackson-Vinton Community Action, Midwest Logistics Systems, NW 33 Innovation		

AUDIENCE TYPE	ENTITIES	ROLE	OUTREACH*
	Corridor Council of Governments (COG), The Diabetes Institute, TRC, University of Cincinnati		
State safety and law enforcement	Buckeye State Sheriff's Association (BSAA), Ohio Department of Public Safety (ODPS) and Ohio State Highway Patrol (OSHP)	Identify rural transportation challenges and end user needs, share experiences, provide general demonstration feedback and support demonstration	End user needs focus group and/or briefings, solicitation of input at existing meetings
Logistic councils, port authorities	Columbus Region Logistics Council, Dayton Logistics Council, Southeastern Ohio Port Authority	Provide subject matter insight, provide end user needs	Solicit end user needs at existing meetings
Trucking and shipping trade associations	American Trucking Association (ATA), National Private Truck Council (NPTC), Ohio Trucking Association (OTA)	Provide subject matter insight, provide end user needs	End user needs focus group
Trucking companies and autonomous vendors	Freight carriers and shippers, Paccar, Asymmetric Technologies	Provide subject matter insight, provide end user needs	End user needs focus group or one-on-one interviews
Stakeholders			
County and local agencies/officials	Athens County Commissioners, Athens County Engineer, City of Athens (mayor and council), Village of McArthur (mayor and council), Vinton County Commissioners, Vinton County Engineer	Provide end user needs, Listen and share experiences, provide general demonstration feedback, build ownership and excitement in demonstration outcomes	End user needs focus group and/or briefings, solicitation of input at existing meetings
Local law enforcement and first responders	Athens County EMS, Athens County Sheriff's Office, Vinton County EMS, Vinton County Sheriff, City of Athens Fire Department, City of Athens Police Department, Village of McArthur Fire Department	Identify rural transportation challenges and end user needs, share experiences, provide general demonstration feedback and support demonstration	End user needs focus group and/or briefings, solicitation of input at existing meetings
Heath & wellness agencies and organizations	317 Board, Athens City-County Health Department, Athens County Board of Developmental Disabilities, Athens County Department of Job and Family Services,	Provide end user needs, listen and share experiences, provide general demonstration feedback	Briefings/solicit input at existing meetings

AUDIENCE TYPE	ENTITIES	ROLE	OUTREACH*
	Athens County Food Pantry, Campbell's Market (McArthur), HAPCAP, Kimes Nursing and Rehabilitation Center, OhioHealth O'Bleness Hospital, The Laurels of Athens, Maple Hills Skilled Nursing & Rehabilitation, Vinton County Department of Developmental Disabilities, Vinton County Health Department, Vinton County Job & Family Services, Vinton County Senior Citizens, area councils of aging		
Educational institutions and organizations	Building Bridges to Careers, Hocking Technical College, NHTSA AV Test, Ohio STEM Learning Network Southeast Region (led by Ohio University), Ohio University, Ohio University - Professional Autonomous Vehicle Engineers (PAVE) group, University of Cincinnati	Provide end user needs, listen and share experiences	Briefings/solicit input at existing meetings
Regional business advocacy	Athens County Economic Development Council, Athens Area Chamber of Commerce, Athens-Meigs County Farm Bureau, Jackson-Vinton County Farm Bureau, Lawrence Economic Development Corporation, Ohio Means Jobs - Athens County, Vinton County Development Department	Provide end user needs, listen and share experiences, provide general demonstration feedback	Briefings/solicit input at existing meetings
Other local, state/regional agencies/organizations	Appalachian Regional Commission (ARC), Athens County Extension Office, Athens County Regional Planning Commission, Ohio Farm Bureau, Gallia County Engineer, Lawrence Economic Development Corporation, Ohio Governor's Office of Appalachia, Ohio Turnpike	Provide end user needs, listen and share experiences, provide general demonstration feedback	End user needs focus group or briefings/ solicitation of input at existing meetings

AUDIENCE TYPE	ENTITIES	ROLE	OUTREACH*
	Commission, Public Utilities Commission of Ohio (PUCO), SIXMO, Sustainable Energy Solutions, Vinton County Extension Office		
Public			
Public officials (and grant partners)	Ohio House of Representatives, Ohio Senate, US House of Representatives, US Senate	Inform and influence policy, provide general demonstration feedback, build ownership and excitement in demonstration outcomes	Briefings/solicit input at existing meetings
Other road users	AAA Ohio, ODOT communications and TSMO staff at Central Office and District 10, OHGO, Ohio LTAP	Educate the public and members	On-road signage, OHGO, radio/TV traffic reports, social media, earned media coverage
Media outlets	Local, regional, statewide and national media outlets	Educate the public, industry and peers	News releases, media events, talking points

See the Engagement Strategy & Methods section for more detail

Messaging

An overall “umbrella” or “elevator” message for the ADS demonstration will explain the who, what, why, how and when. Sub-messages will detail the truck and passenger vehicle automation demonstrations. These messages will serve as the foundation for all deliverables and communications throughout the life of the effort. Materials will range from news releases and presentations to fact sheets and final reports. The process of creating these approved messages ensures everyone is on the same page and that all audiences hear one consistent message. This builds understanding over time.

Automated Driving Systems

Testing automated trucks and passenger vehicles in rural Ohio

DriveOhio’s Automated Driving Systems project will demonstrate how automated trucks and passenger vehicles could improve safety for drivers, passengers and other travelers in rural settings.

While automated driving systems have been tested in urban areas, there is much yet to learn regarding how automated vehicles operate in rural environments. As a microcosm of the U.S., Southeast Ohio serves as the ideal testbed to collect data due to its four-season climate and a diverse landscape of level and steep terrain.

The U.S. Department of Transportation (USDOT) awarded the $7.5 million ADS Demonstration Grant to the DriveOhio-led team of the Transportation Research Center (TRC), JobsOhio, AutonomouStuff, University of Cincinnati (UC), Bosch and Ohio University (OU). The Federal Motor Carrier Safety Administration (FMCSA) is administering the grant.

Demonstration findings will help define technology needs and limitations as well as inform the safe scaling of future vehicle automation deployments in the U.S.

Transportation challenges are magnified in rural areas like Appalachian Ohio. Lack of public transit options, longer travel distances and limited internet access are just a few of the hurdles. Roadway challenges for automated vehicles include moving from shaded areas under tree canopies to bright sunlight, for example, and limited sight distances around curves or over hills.

COMMUNICATION TOOLS

Once the brand and messaging are finalized, the following communication tools will be developed to facilitate understanding of the demonstrations to audiences, stakeholders and the public.

Microsite

A microsite for the ADS demonstration is housed on the DriveOhio website. These web pages will serve as an easy to access repository for study information, which reinforces transparency. The microsite will provide:

- An overview of the demonstration purpose, goals and schedule
- Frequently asked questions
- Demonstration project documents as appropriate
- Announcements of when testing will occur, as appropriate

- Presentations/webinar materials

As the microsite is being developed, DriveOhio will reach out to the NHTSA AV test website developers to determine if there are opportunities to cross link to each site's web pages or if there are other opportunities for information sharing.

Presentations

Using the approved brand and messaging, a PowerPoint presentation template will be developed in audience-friendly language and graphics that explains the demonstration goals, possible test areas, process and schedule. Further iterations of the presentation will be developed as the demonstration progresses and customized to the audience receiving the presentation. The presentation could be given at end user stakeholder interviews, community briefings and future learning exchanges and conferences. PDF versions of presentations will be posted to the demonstration microsite.

Fact Sheets

Using the approved brand and messaging, an overview fact sheet will be created. It will tell the demonstration story in a clear and concise way and include demonstration goals, map, process and schedule. Fact sheets will address questions commonly asked by the public, including whether the autonomous vehicle (AV) and personal data is safe, what is AV technology and how does it work, what are the benefits of AV technology, how will demonstration data be collected and how will the team store, manage and use this data during and after the demonstration?

Additional project-specific fact sheets may be created highlighting various aspects of the automated transportation solutions once they are further developed (including route maps, etc.). PDF versions of all fact sheets will be available for public download on the demonstration microsite.

Playbook

Once the demonstrations are fully defined and being implemented, the ADS Demonstration Playbook will be developed to share learnings and best practices in one place for other ADS decision makers locally, nationally and internationally. The Playbook will be a living digital archive of automated transportation safety data collection findings in rural areas. It will contain archived documents that other ADS decision makers may leverage, as well as firsthand perspectives from the project team on what worked, what didn’t, why, and what other rural regions can learn as they pursue similar initiatives. Entries about the testing and data gathering of automated transportation solutions will be posted as progress warrants and aimed at reaching government policy makers, vehicle researchers and engineers as well as any others interested in automated driving systems.

Demonstration Database/Stakeholder Register

A stakeholder register and contact database will be created and updated during the life of the ADS demonstration. The register will include email contacts generated to solicit end-user needs and also include contacts from other interested partners, stakeholders and the public requesting notification about announcements, briefings and updates.

eMessaging/Public Announcements

Electronic messages or e-news updates will be developed and sent to the contact database/stakeholder register on an as-needed basis. eMessaging and e-news content may also be used to notify stakeholders when new demonstration materials or other information has been posted on the demonstration microsite. DriveOhio will ask its partners to share these updates via their distribution channels as well.

Talking Points/Media Outreach

At various milestone during the development and deployment of the demonstration, talking points and potential news release content will be developed. DriveOhio and/or ODOT District 10 will serve as the lead spokespersons and media contacts and will finalize/distribute news releases in collaboration with partners and local officials as appropriate.

Social Media Messages

To prepare the public for when vehicle testing begins on local roadways, a non-paid social media campaign will be developed to explain what is happening. Social media posts and images will be provided to DriveOhio, ODOT District 10 and other local partners to share on their existing social media platforms.

Highway Signage

Similarly, to prepare the public for when vehicle testing begins on local roadways, roadside and vehicle signage may be required (following Manual on Uniform Traffic Control Devices guidelines) to explain what is happening. Logistics and production needs will be determined in partnership with DriveOhio, ODOT District 10 and local transportation officials. ODOT will produce and post the signs.

OHGO

ODOT's OHGO travel app may also be a resource that can be used to communicate to travelers where demonstrations are operating. ODOT's TSMO coordinators and public information staff will be consulted on how protocols for distributing public information on OHGO.

INTERNAL COMMUNICATION

As summarized in the ADS Project Management Plan, the project team will meet regularly over the life of the demonstration through weekly update meetings with DriveOhio, weekly demonstration work sessions and other meetings detailing specific demonstration needs. Additional communication channels and protocols will occur for monthly and quarterly reporting to DriveOhio, USDOT and FMCSA. Internal team meetings may also occur prior to any planned end user, stakeholder or public engagement activities.

EXTERNAL COMMUNICATION AND ENGAGEMENT

While the main objective is to collect ADS safety data from rural roads, external communication and engagement will occur to collect end user need data and inform partners, stakeholders, the media and the public about the demonstration. An overview of engagement strategies is located in the following ***Engagement Strategy & Methods*** section. Specific stakeholder communication and engagement information and strategies to collect end user needs for each demonstration can be found later in this plan under the ***End User Stakeholder Management Plan***.

ENGAGEMENT STRATEGY & METHODS

The following section outlines the engagement strategy and methods for the ADS demonstration. The following methods will be used:

ADS Project Executive Board Briefings

DriveOhio has formed an ADS Project Executive Board that includes representation from DriveOhio, TRC, ODOT, JobsOhio and Ohio Governor Mike DeWine's Office. The Executive Board's role is to stay informed and engaged through quarterly reports and interim demonstration updates provided by DriveOhio and the project team.

End User Needs Solicitation: Interviews, Focus Groups, Briefings at Existing Meetings

A series of interviews and focus groups will be held to collect end user needs from both internal and external stakeholders for the truck and passenger vehicle demonstrations. Project-specific end user needs solicitation is outlined in the ***End User Stakeholder Management Plan*** section below.

Community Briefings

Briefings at existing meetings will be provided to various entities to provide information about the demonstration and potential longer-term outcomes, solicit input and respond to questions from local leaders. As needed, DriveOhio may convene community stakeholders to solicit specific input related to the demonstration's development and deployment.

Community Forum

Initially, one virtual community workshop may be held in Summer/Fall 2021 to explain the demonstration and solicit longer-term user needs. Invitees may include:

1. ADS peer groups and organizations, including Jobs Ohio, NW 33 Council of Governments (COG), Ohio University, City of Athens, Buckeye Hills Regional Council, Ohio Southeast Economic Development
2. County and local agencies/officials, including Athens County Commissioners, Athens County Engineer, City of Athens (mayor and council), Village of McArthur (mayor and council), Vinton County Commissioners, Vinton County Engineer
3. Heath & Wellness agencies and organizations, including 317 Board, Athens City-County Health Department, Athens County Board of Developmental Disabilities, Athens County Department of Job and Family Services, HAPCAP, OhioHealth O'Bleness Hospital, Vinton County Department of Developmental Disabilities, Vinton County Health Department, Vinton County Job & Family Services, Vinton County

Senior Citizens, area councils on aging and transportation providers, Campbell's Market (McArthur), Athens County Food Pantry

4. Educational institutions, including Ohio University, Hocking Technical College and University of Cincinnati, Ohio STEM Learning Network Southeast Region (led by Ohio University), Building Bridges to Careers, Ohio University - Professional Autonomous Vehicle Engineers (PAVE) group
5. Regional business advocacy including, Athens County Economic Development Council, Athens Area Chamber of Commerce, Athens-Meigs County Farm Bureau, Ohio Means Jobs - Athens County, Vinton County Development Department, Jackson-Vinton County Farm Bureau
6. Other local, state/regional agencies/organizations including, Appalachian Regional Commission (ARC), Athens County Extension Office, Athens County Regional Planning Commission, Foundation for Appalachian Ohio, Ohio Farm Bureau, Ohio Governor's Office of Appalachia, Public Utilities Commission of Ohio (PUCO), Vinton County Extension Office

Additional community forums and public meetings may be held at future dates.

Shared Learning Community

A key objective of the ADS demonstration is to share lessons learned with other decision makers and federal government officials to inform future automated transportation projects. Throughout the demonstration's development, successes and lessons learned will be documented so that others can use the information as a roadmap for their evaluation, planning and execution of similar efforts. We will share information and compare lessons learned with them during demonstration development and post-deployment.

Webinars

The ADS demonstration will periodically participate in public FMCSA and USDOT-organized webinars on program progress, performance and lessons learned. Therefore, throughout the life cycle of the testing demonstrations, presentation materials will be updated to encapsulate the problem, solution and goals in preparation for these peer learning opportunities.

Conferences/Tradeshows

The ADS demonstration team may attend a select number of future workshops, conferences or tradeshows each year. Early in the program, the purpose of attending these events is to learn best practices, whereas in later program years the purpose is to share progress updates and lessons learned.

Professional Associations/DriveOhio Alliance

Similarly, lessons learned as the ADS demonstration progresses and is completed will be shared with peers, industry associations and the DriveOhio Alliance. The Alliance is an informal group of local, regional and state officials and public and private organizations throughout Ohio and across the U.S. who are interested in smart mobility initiatives. There are currently 500+ members of this group, which is open to anyone.

Future End User Outreach

The ADS demonstration team may hold future engagement opportunities with future STEM workforce audiences where possible, to engage and inspire the K-12 emerging workforce and higher education students. These meeting would be held in coordination with Ohio STEM Learning Network Southeast Region at Ohio University, Building Bridges to Careers in Marietta and student groups like the Professional Autonomous Vehicle Engineers (PAVE) at Ohio University.

END USER STAKEHOLDER MANAGEMENT PLAN

PLAN OVERVIEW

This stakeholder management plan outlines a series of proactive steps to ensure end user input research is gleaned efficiently and reflected in the Concept of Operations for both truck and passenger vehicle automated demonstrations. This effort will also provide input on transportation end user and provider needs and guide the solicitation of the constructive feedback necessary to shape and confirm the safe integration of automated driving systems onto our nation's roadways, while also positioning Ohio's Appalachian Region to be a national leader in rural AV innovation.

TRUCK AUTOMATION

Demonstration Description

Teaming with Transportation Research Center (TRC), Bosch and a yet to be named host fleet partner, DriveOhio will test partial, Level 2 truck automation technology, including tractor semi-trailer "platoons" where two tractor semi-trailers travel closely together. Trucks with Level 2 automation can control both steering and accelerating/decelerating, but a driver sits in the tractor's seat and can take control at any time. Each tractor will have an engaged operator at all times to oversee safety and functionality and to drive when the two trucks are not in platooning mode.

Data will be collected while platooning or in single tractor mode as the automated trucks operate on different types of roads in different weather conditions. This will help researchers understand how automated trucks perform in real-world situations.

In addition to those cited above, partners include JobsOhio, UC, OU, OhioSE, NW 33 Council of Governments (NW33 COG), freight industry stakeholders and local entities.

Automated trucks may benefit the freight industry through improved safety, fuel economy and operational efficiency. Lower emissions may also result. DriveOhio will work with freight industry leaders and local communities to understand safety needs, concerns and constraints with emerging technologies. Demonstration findings will help define technology needs and limitations to better serve the safe operation of the trucking industry.

Engagement Strategy & Approach

A structured approach will be used to solicit user needs related to truck automation. A series of specific questions to collect user needs will be developed and included in a moderator's guide to be used during interviews and focus groups, as outlined below.

- One-on-one interviews with trucking companies and autonomous vendors that may be interested in participating; interview with FMCSA and its partners
- Focus groups with:
    1. DriveOhio/ODOT, including ODOT District 10, other ODOT Divisions (Communications, Data Governance, DoIT, Highway Safety, Legal, Operations, Planning/Freight, Transit) and the Ohio Freight Advisory Committee
    2. State safety and law enforcement, including Ohio Department of Public Safety (ODPS) and Ohio State Highway Patrol (OSHP), Buckeye State Sheriff's Association (BSAA), CVO Enforcement/Safety or Ohio State Highway Patrol Motor Carrier Enforcement Unit
    3. Local safety and law enforcement and first responders, including Athens County EMS, Athens County Sheriff's Office, Vinton County EMS, Vinton County Sheriff, City of Athens Fire Department, City of Athens Police Department, Village of McArthur Fire Department

       As the three groups above overlap with automated passenger vehicle focus groups, half of the focus group content will focus on truck automation end user needs and half will focus on automated passenger vehicle end user needs.
    4. Trucking and shipping trade associations and logistics councils, including Ohio Trucking Association, Buckeye Hills Regional Council, Central Ohio Logistics Council and Southeastern Ohio Port Authority,

Once the interviews and focus groups are completed, end user needs will be tabulated, and a limited number of emerging user scenarios will be developed by the project team based on end user and stakeholder input. Stakeholder end user needs will be tracked throughout the systems engineering process. Additional interview may be scheduled – including with the Dayton Logistics Council.

Truck Automation User Needs Schedule

- April 2021
    - Finalize user needs interview and focus groups invitation list
    - Finalize ADS and demonstration-specific messaging
    - Schedule dates; send invitations
    - Develop/finalize moderator's guide and discussion exercise details
    - Develop/finalize fact sheet

    - Convene focus groups/briefings starting April 26
- May 2021
    - Continue focus groups/briefings up to May 14
    - Document and report results May 31
- July 2021
    - Follow-up focus group with southeast Ohio officials and freight groups

PASSENGER VEHICLES AUTOMATION

Demonstration Description

DriveOhio will also test automated passenger vehicles in Athens and Vinton counties. These vehicles equipped with AutonomouStuff technology stacks will have Level 3 automation. Level 3 autonomy means the vehicles can make informed decisions for themselves, such as accelerating past a slow-moving vehicle, but they still require a human override.

Data will be collected as the automated passenger vehicles operate on divided highways and rural two-lane roads between Athens and McArthur. They will be tested in differing operating and environmental conditions, including periods of limited visibility and in work zones. A driver will be behind the wheel at all times to monitor operations and to intervene as needed.

Safety needs, mobility challenges and specific routes will be confirmed by soliciting input from partners and local communities. Partners include TRC, AutonomouStuff, JobsOhio, OU, UC, OhioSE and stakeholders in Vinton and Athens counties.

Access to healthcare, jobs, goods and services can be significant challenges for those living in rural areas. Automated transit vehicles may improve access and mobility options, improving quality of life. Demonstration findings will help define technology needs and limitations as well as inform the safe scaling of automation on future deployments in the U.S.

Engagement Strategy & Approach

Based on the needs and goals of the demonstration, a structured approach will be used to solicit user needs related to automated passenger vehicles. A series of specific questions to collect user needs will be developed and included within a moderators guide used during focus groups. These strategies are outlined below.

- Focus groups with:
    1. DriveOhio/ODOT, including ODOT District 10, other ODOT Divisions (Communications, Data Governance, DoIT Freight, Highway Safety, Legal, Operations, Planning/Freight, Transit)
    2. State safety and law enforcement, including Ohio Department of Public Safety (ODPS) and Ohio State Highway Patrol (OSHP), Buckeye State Sheriff's

Association (BSAA), CVO Enforcement/Safety or Ohio State Highway Patrol Motor Carrier Enforcement Unit

3. Local safety and law enforcement and first responders, including Athens County EMS, Athens County Sheriff's Office, Vinton County EMS, Vinton County Sheriff, City of Athens Fire Department, City of Athens Police Department, Village of McArthur Fire Department

   As the three groups above overlap with truck automation focus groups, half of the focus group content will focus on truck automation end user needs and half will focus on automated passenger vehicle end user needs.

- Briefing/solicitation of user needs at existing meetings

  During the initial outreach, it may be determined that the groups above have regular gatherings where a briefing could be provided, and input solicited. Briefings could be in addition to, or in lieu of, a DriveOhio-convened focus group.

Once the focus groups are completed, end user needs will be tabulated, and a limited number of emerging user scenarios will be developed by the project team based on end user and stakeholder input. Stakeholder end user needs will be tracked throughout the systems engineering process.

Automated Passenger Vehicles User Needs Schedule

- April 2021
  - Finalize focus group and workshop invitation lists
  - Finalize ADS and demonstration-specific messaging
  - Schedule dates, send invitations
  - Develop/finalize moderator's guide and discussion exercise details
  - Coordinate ADS discussion and user needs collection at existing meetings
  - Develop/finalize fact sheet
  - Convene focus groups/briefings starting April 26
- May 2021
  - Continue focus groups/briefings up to May 14
  - Document and report results May 31
- July 2021
  - Follow-up focus group with southeast Ohio officials and freight groups

Appendix C2
Automated Driving Systems (ADS) Demonstration-End User Needs Input Summary Report

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration

Testing Automated Trucks and Passenger Vehicles in Rural Ohio

End User Needs Input
Summary Report & Appendix

June 16, 2021

(updated with July 21, 2021 Focus Group information)

MURPHYepson

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio

End User Needs Input Summary Report

June 16, 2021 (updated with July 21, 2021 Focus Group information)

INTRODUCTION

While automated driving systems (ADS) have been tested in urban areas, DriveOhio's ADS project will collect data from both automated trucks and passenger vehicles in rural environments. The data will be used to inform state and federal rule-making, with the ultimate goal of improving the mobility, operation and safety for drivers, passengers and other travelers in rural settings.

DriveOhio's ADS project involves engaging end users (those that may benefit, govern or interact with this emerging technology) to determine their needs and identify their ideas and concerns.

To that end, a series of seven focus groups were conducted between April and July 2021. Participants included representatives from national, state, regional and local organizations that may interact with the projects. The focus groups had the additional benefit of creating awareness and understanding of the ADS demonstration.

END USER NEED PARTICIPANT AGENCIES & ORGANIZATIONS

The following list highlights those agencies and organizations that participated in the end user needs focus groups for both truck and passenger vehicle automation.

- Buckeye Hills Regional Council
- Central Ohio Logistics Council
- City of Athens (Council, Fire and Police Departments)
- DriveOhio
- Federal Highway Administration (FHWA)
- Federal Motor Carrier Safety Administration (FMCSA)
- Federal Transit Administration (FTA)
- Gallia County Engineer
- Ohio Department of Public Safety (ODPS)

- Ohio State Highway Patrol (OSHP)
- Ohio Department of Transportation (ODOT), Central Office
- ODOT District 10
- Ohio Trucking Association
- Ohio University
- SIXMO City Services
- Southeast Ohio Port Authority
- Terra Sound Technology

Other groups that were invited but unable to participate in the focus groups are shown below. Additional community and stakeholder engagement activities to inform and solicit feedback will continue throughout the demonstration.

- Asymmetric Technologies
- Athens County Engineer
- Athens County EMS
- Athens County Sheriff
- Buckeye State Sheriff's Association (BSAA)
- City of Athens Fire Department
- City of Athens Police Department
- Lawrence Economic Development Corporation
- ODOT District 10 Garage Managers
- South East Ohio Port Authority
- Village of McArthur Fire Department
- Village of McArthur Police Department
- Vinton County Engineer
- Vinton County Sheriff

FOCUS GROUP FORMAT

A professional facilitator moderated each focus group. Each session included introductions, a recap of the project goals and a brief presentation to build awareness and understanding of the ADS demonstration. This was followed by a series of questions to seek input on end user needs for truck and passenger vehicle automation and other project inputs. The questions were structured with flexibility in mind so that attendees to inform the flow of the conversation. As more focus groups were conducted, the questions evolved to reflect the issues stakeholders and end users seemed to care about the most. A sample of the presentation, moderator's interview guide and individual focus group meeting summaries are provided in the appendix.

SUMMARY OF END USER & STAKEHOLDER INPUT

The following is a summary of end user needs, observations and other input. This includes comments, questions and key takeaways from all seven focus groups. User input is sorted by truck or passenger vehicle automation under the following six categories:

Category	*Description*
Vehicle Automation	• Automation, function and operational needs of the vehicle
Vehicle/Roadside Infrastructure Communication/Routes	• External data and communication needs, including vehicle to vehicle and vehicle to roadside infrastructure considerations • Route suggestions
Operational Uses	• Business cases, fleet and operator needs, return on investment considerations
Safety & Enforcement	• Safety and law enforcement concerns and needs
State & Federal Policy	• National, state and local policy needs
Community Impacts/Communication	• Societal benefits • Stakeholder engagement and education needs and suggestions

Truck Automation User Needs/Input *(Includes Questions and Comments from Stakeholders)*

Vehicle Automation

- Do you have the freight density to justify platooning, or data on the distance needed between two trucks yet?
- See the NHTSA report on braking distance and its functional safety study in Level 2 automation mode. It walks developers through the standards.
- What is your grant not going to answer that FMCSA/USDOT could address, and can your budget handle it?
- Driver fatigue and the operation value to the fleet is important to understand. That will help the trucking industry understand the return on investment, and whether this is worth the investment. That's what we (FMCSA/FHWA) are curious about.
- Also, we (FMCSA/FHWA) have done some video-based sensors of the brainwaves of drivers. It's okay to duplicate what FMCSA/USDOT is doing in the California/NM/Texas study; more data is good. We're still figuring out what we don't know yet.
- Also, see the Virginia Tech cookbook on how to integrate AV trucks into a regular fleet. Ask the fleet host what their maintenance concerns might be.
- Freightliner and Bendix are about to manufacture Level 2 trucks, but they won't be available until 2021. Platooning is not yet in production.

- Also consider how to counter boredom and complacency. It would be very helpful to us to get this kind of operational data.
- I hear that additional sensors are helpful for operators; they help with maneuverability.
- If a test case is done rather than on an actual road, bricks of concrete can be loaded in to simulate cargo weight without chancing it with live cargo; in fact, truckers will often keep ballasts full of water in empty trailers if they are light and it's windy out. It's the cargo, not the truck that matters from a cost perspective; for example, a truck of chickens is valued at 80k.
- For a single truck, lane keeping is already fairly common on trucks; some of the bells and whistles are already on the newer trucks so the question is what's the value-add of all of these together? There will be people who wonder how this is any better because it can be clunky at times.]
- What is your evaluation trying to get to? Striping, etc. Will striping and wax sealing in the area be an issue?

Vehicle/Roadside Infrastructure Communication/Routes

- Truck information will be helpful to local logistics/freight companies.
- I'm concerned that the technology has so many limitations that it's basically just adaptive cruise control on steroids; there are real weaknesses to platooning and very rare cases where the operation makes sense.

Operational Uses

- For truck platooning, ask the fleet operator what systems they have to measure fuel savings, productivity savings and the safety benefits for the second driver. Also, ask them how they communicate. Talk through collecting data on these benefit areas.
- Concerned about the wearing surfaces of roadways and future uses of these ADS technologies. For example: there is a booming log cabin business with homes being sold across the county and these are being built along the roadside and materials are being delivered by an influx of trucks (load after load). Is the ADS project/team looking into this?
- The ADS demonstration is approaching the shale (oil) region (in Eastern Ohio) and this industry employs multiple water trucks for its operation. Consider partnering with this industry with truck platooning.
- ADS technology will be a hard sell for traditional companies to think about using, so the earlier this effort is publicized the better.
- A market situation and tech reality are two different things; it may be tech feasible but there may be no business case for it.

- In the industry, there are questions on whether competitors could platoon off one another (leeching). There is a lot of industry chatter about how many trucks maximum is allowed to platoon at one time.
- Workforce: There is a (potential employees') fear of operating large vehicles and that is a barrier to some people choosing to become "truckers" – to find the needed talent at a time when there is a driver shortage, this has the potential to bring in additional people.
- In regard to the general public (and potential employees), large machinery and manual transmission understanding is more limited now than ever and that can be a real barrier to obtaining new drivers (especially at a time when the industry is already facing a driver shortage and a number of drivers are expected to retire soon); one potential benefit of autonomous technologies is that it could expand the net of interested talent; there are truckers who are used to tight corners and congestion, but most are not.
- Platooning is not practical in rural settings because two full trucks aren't stopping in the same place; suggested doing fake scenarios at TRC rather than in revenue settings (freight could be faked for weight in the truck).
- Could one goal of the demonstration simply be exposing the industry to the technology realities?
- It will be no problem to find a host fleet, but the travel area is important. Most importantly, it has to make business sense for the fleet operator to participate.
- May be most advantageous for time-critical and high-quantity deliveries such as fuel haulers or animal food haulers.
- The goal here should be more about what the business case for automation is – a cost/benefit analysis as well as the safety and research would be beneficial.
- Are these full-size tractor-trailers? Some weight considerations if trucks go into town.

Safety & Enforcement

- We are working with Roly's Trucking, which is based in California, for a demonstration there. They purchased trucks and FMCSA/USDOT leased the trucks from them. They are doing a 1,400-mile test route from California to New Mexico to Texas. My advice is to involve the state patrol as soon as possible and keep them involved early and often, even if you don't need specific input. In California, they asked that we put an indicator light on the trucks when they are in platooning mode.
- Confirm the laws on following distance in Ohio and get a waiver if you need it. The state patrol will know all about these types of issues and will raise them.

State & Federal Policy

- The team should think about what license plates they'll use or what type of permitting will be needed for ADS vehicles. We've discovered this is a sticky issue. Get the DMV and DPS involved early.
- Regarding insurance concerns, Roly's Trucking has been so supportive in other ADS efforts. CPASS meets with them every other week, and they learn so much. I would advise the ADS team to do the same. Insurance is not an issue because they are using their own trucks. We did have to train their drivers. Training documents and materials can be shared by FMCSA/USDOT in a few weeks. Lessons learned from this effort can also be sent to the team towards the end of the year. This should be a big help since you won't start until about a year later.
- Glad Cynthia (DriveOhio) and the CDM Smith team will serve on any ADS expert panels coming up; FMCSA/USDOT would like to see all eight ADS grants learn from each other. We are very excited this is all getting started. We'd love to see all the grants in a chart that summarizes the projects, which ones Carma is on, etc.
- I'm interested in who will publicly take a leadership role as the owner of the automation conversation, i.e., who is doing what first?
- From a policy point of view, there's a concern that autonomy will take away existing jobs; there's also a concern about the safety of other road users (especially if they attempt to cut in between two platooning trucks).
- Cargo insurance is substantive so that may be an element of the demonstration that presents a challenge.

Community Impacts/Communication

- Concerned about the number of trucks and platoons. Routes like US 35 already have high truck traffic; truck stops are at capacity and trucks are parked on the sides of the roads (overnight) all along US 35.
- I know the ADS team is looking at testing on US 33, but US 35 has a higher percentage of truck traffic than I-70. East of Columbus, (when the WV section is reconstructed) there will be a 4-lane highway to and from Charleston. Maybe this is a route to look at for the ADS demonstration?
- This tech will also tell ODOT where infrastructure can be improved; and help inform traffic managers.
- Workforce development is a really big deal – freight matters in Ohio. Is there an opportunity for a talent fair that also helps bring about excitement in younger people (a larger talent pool)?
- Trade schools might get excited about an opportunity to engage.
- Get tech/fleets together for a career day.
- Do a ride-along at the TRC test track or during the demonstration, if possible, to help professionals and electeds understand where the technology is right now.

- What will the signage and/or communications be to drivers and the public? This is important.

Passenger Vehicle Automation User Needs/Input *(Includes Questions and Comments from Stakeholders)*

Vehicle Automation

- Concerned about Level 3 automation. Aviation studies show it takes 10 seconds for a human to react and take over an automated function. It's advised that when drivers are asked to monitor automated functions, driving time durations need to be kept short to lessen driver fatigue or boredom, which may slow reaction time. ADS should review the recent research on this and see SAE recommendations.
- Will the demonstration have passengers?
- Concerned that 3-4 passenger vehicles platooning close together could be disruptive to the public; this depends on where the demonstration occurs and what routes they are traveling on. Where will the deployment take place?
- If a pooling of automated vehicles were in close proximity at one of the 10 most dangerous intersections, that might be too much for the public at large; but if they are traveling on straighter state routes this shouldn't be a problem.
- Automation is not distracting as long as there are "drivers". Once we remove the "person" that becomes more alarming. I don't think 3-4 passenger vehicles are going to tip over the apple cart from the public perspective.
- How will automated passenger vehicles operate with freight traffic that regularly travels these roads?
- Concerned with the camera system in terms of seasonality. Snowfall could affect the spatial location of cameras—are there any safety considerations?

Vehicle/Roadside Infrastructure Communication/Routes

- Regarding mapping, you'll need to get feedback from AutonomouStuff on operational parameters for routing.
- Bosch has good input on vehicle routing requirements along with AutonomouStuff. FMCSA will want to review and weigh in on ADS test plans. This demonstration's plans should complement what the other ADS projects are doing nationally, and we want to encourage collaboration.
- How does the vehicle communicate its intent to other road users and vulnerable road users? This input will be very helpful across the U.S.
- Demonstration should consider the following navigation issues and routes:
    - Navigation that truckers use often leads them to dead ends.
    - Test grades between State Street and US50 on US33.

- Baker Road at US50 between Athens - this area is narrow and windy with no pavement markings.
    - US 50 East to US 33 East.
    - US 33 and US 50 (between 33 and 32), from 32 to McArthur.
    - Consider looking at the test section on US 50 west of McArthur even though this might be out of the region being considered; there is extra right of way there due to the testing which may be helpful.
    - There are no areas to stay away from in my point of view.
    - To inform the route or place to avoid, use TOAST data (it has information on impacts); the TMC also has anecdotal info – and access to WAZE data.
    - There are four at-grade intersections we've worked on including Athens at Blackburn Road, US 50/CO/9 intersection, and township 38/united lane to look into.
    - 278 and 356 are each prone to frequent flooding so that's a consideration for the project team.
    - US 50 is pretty consistent but there are a lot of closures.
    - Operationally, do not test around Athens/Alexander High School off of US 50 and New Albany. There is a lot of congestion at the turning movements.
    - South of Athens, there is limited access on 33 south to north of Pomeroy. It was built to four-lane standards but currently is at two lanes.
    - Most of the test route isn't located in the City of Athens jurisdiction. You will need to talk to the county commissioners and Athens and Alexander township trustees.
    - The proposed test route is within the Athens Fire Department jurisdiction and some other volunteer jurisdictions; Athens FD has a mutual aid response in those jurisdictions. This loop gives you what you're looking for in road variety and there are no issues with school jurisdictions or EMS.
- This area is part of the state's strategic freight network.
- EIMS – the project team could choose to look into the existing animal carcass/strike information we have on state routes as a resource. (Matt Bruning sent the link.) ODOT will share capital program information for the team to use.
- Be aware of the ROADMAP program, which is a Dept. of Energy Grant. It will look at electric public transit vehicles and also use a Tesla to test some (level 2) automation in the Athens area.
- Make sure there is no personally identifiable info relayed.
- I would like to see schema once data streams are operating to see if/how the new data is being managed. See the ODOT Data Governance Plan.

Operational Uses

- Glad this effort will engage local officials. Manufacturers are also interested in understanding the ADS operational scenarios for example. There are also concerns from local law enforcement, emergency responders, local weigh stations, etc.

- NOTE: all FTA (public transit) operations need to be ADA-compliant, but this demonstration won't need that compliance since you aren't carrying any members of the public. For reference, the Western Reserve Transit Authority project in Youngstown is also looking at automated functions for ADA services.

Safety & Enforcement

- Should this ADS demonstration include a local law enforcement plan?
- What resources and reassurances do safety officials need to trust ADS operations and testing on public roads?
- Consider asking EMS and other safety providers for their concerns on how ADS vehicles will function with their vehicles and in emergency situations.

State & Federal Policy

- None.

Community Impacts/Communication

- What is the rationale behind platooning passenger vehicles in a rural environment? Is there a need?
- As an example of other ADS-related initiatives: A Contra Costa County hospital system is coordinating a wheelchair-lift-equipped shuttle service using Level 3 and 4 automation, which travels up to 50 mph. It is one of three projects in Contra Costa County that kicked off in April 2021.
- The ADS project team should ask transit agencies how their passengers would feel utilizing ADS vehicles, and consider interactions between ADS vehicles, the public, pedestrians and bicyclists.
- The most exciting aspect of the ADS demonstration is advancing mobility options in southeast Ohio rural areas including overall economic opportunities for rural areas.
- There are mobility barriers to rural populations including the aged, at-risk, (those in) substance abuse recovery and (people with disabilities).
- This demonstration will allow for more mobility options and opportunities to get transportation services to these at-risk populations that don't require a lot of overhead (drivers, multiple passengers per trip, etc.).
- There is a lot of optimism for the next 'Big" thing (i.e. future mobility uses in rural Ohio); we need to realize there are several folks currently not utilizing our transportation networks in rural communities.
- Currently there are not many options for those who need transportation on demand (at random times during the day, for work or appointments, etc.)
- The community needs to understand these mobility opportunities are down the road but not that far off (less than 50 years).

- Transit clients may be nervous; it will depend on providers to ensure safety and whether (customers) will accept the technology.
- HAPCAP has a large program – maybe operate fleets at OU campus? They would be a good partner. Keep them engaged.

Overlapping Truck & Passenger Vehicle Automation User Needs/Input *(Includes Questions and Comments from Stakeholders)*

Vehicle Automation

- When moving into levels 3 and higher, need to focus on safety driver response time (currently pilots have a 10-second response time, automobiles and trucks need a quicker response time to react to safety issues).
- Demonstration should study safety drivers through monitoring eyes, pressure on steering wheel etc.

Vehicle/Roadside Infrastructure Communication/Routes

- Gallia County has completed an extensive safety study for the entire county, including villages and cities, though not every county has this data.
- When collecting data, note: Buckeye Hills takes out animal crash strikes of data, as there's nothing they can do for countermeasures for public.
- Both passenger vehicle and truck data would be helpful for many logistics organizations.
- Need to consider broadband, connectivity, topography blocking signals (line to line communication), lane markings. Mapping data may come into play (roadway mapping/information isn't very robust in rural areas in US – roadway length, width, speed etc.).
- Need to consider issues with roadway curves, local/county roads, road widths (different road widths/are all over the board), Wi-Fi connection (on Gallia 40% have zero cell service/signals).
- Is it critical that the study pick up/need the road centerline information to operate?
- Gallia County has conducted 4K video (360 degrees) on all roads (plus Lidar); Note: not every county may have this.
- On road surfaces, Gallia County used Ultra 4K to come up with pavement condition ratings and other data. After data was processed, we can measure right-of-way mapping within 1 centimeter of accuracy. Also flew 3-inch aerials.
- Depending on which test routes are chosen, team may want to supplement previous TIMS data regarding striping, lane widths, etc. You'll want the exact status of the roadway at the time of the testing so you can compare apples to apples later.
- Also review SHRP2 and RID data sets and what data those national studies collected.

- Project team asked Derek Troyer (ODOT Office of Safety) to review the ADS Data Management Plan and offer insights. (Similar request was made to John Puente, ODOT Chief Data Officer.)
- State Highway Plan has lots of crash data available.
- How will automated vehicles find driveways?
- How testing will play out?
- Are we testing on gravel roads?

Operational Uses

- What about farm equipment on the roads? How will these vehicles interact with them? Also, what are the implications of the FCC changes? How will that affect V2V and infrastructure?

Safety & Enforcement

- ADS testing should consider wildlife interaction with autonomous testing as there are no countermeasures when interacting with a wild animal. Would not leave this off your list of things to consider.
- When looking at dangerous roadway locations, start with state routes near traffic signals. Though each county's crash statistics should also be reviewed.
- One thing about SE Ohio is that there are lots of hills/curvy terrain and an unprecedented number of guardrails, but there are still many locations without guardrails including township/local roads.
- Should also consider that some roads consist of stones or dirt.
- Advisory speeds along curved roads are not always posted.
- Are you considering winter issues – ice/snow?
- Need to address fallen tree/limbs blocking the roadway.
- Flooding events could be an issue (folks that drive through high water – may be assessed fees for emergencies service if they get stuck).
- Another concern is that smaller roads don't always have edge lines.
- When installing poles/equipment locate them on the inside of roadway curves, which is less destructive. Most vehicles that run off the road, go to the outside lanes.
- Coordinate with ODOT Office of Roadway Engineering when using digital message signs. It's a process.
- Team should work with State Highway Patrol on potential traffic crash investigation/mitigation strategy and train officers.
- Will ADS vehicles be identified or marked, or operate covertly? It is better to mark ADS vehicles, which may build consumer/public confidence and awareness.

- As part of the Six State Trooper Projects (Ohio and neighboring states), SHP is developing and outlining a curriculum for all law enforcement officers, focusing on safety with electric vehicles and automation. Future automation levels 3, 4 and 5 will require a mind-shift on safety and law-enforcement: we'll need to shift to defect investigations, compared to at-fault driver investigations.
- I'm not hearing any red flags from a safety perspective; this seems interesting and exciting.
- TMC oversight will help keep people aware (internally and externally as needed).
- Could we mock-up a work zone if there isn't one already planned for the demonstration route?

State & Federal Policy

- This is a very exciting and tremendous opportunity to test and inform the rest of the US.

Community Impacts/Communication

- There is a large Amish population in Gallia County which has different transportation needs and concerns.
- Prior to ADS demonstration testing, a 30–to 60-day alert is needed to get the word out.
- There is a cool factor to this effort and don't want to see it lost. The sooner the better and as many public outreach opportunities the better.
- This effort will allow for public opportunities to let people learn, see and touch it.
- It is a great opportunity for the SE Ohio region as most testing is in larger cities.
- ADS public outreach contacts should include public officials; county engineers; and transportation managers from groups like Buckeye Hills; and then arming those folks/advocates (with distilled, easy-to-understand information) so they can share it with the public.
- Additional public outreach contacts include Sam Wallace (Buckeye Hills); and Brett Boothe (Gallia County), the Ohio Valley Regional Commission, OMEGA, and Eastgate in Youngstown. Their boards are made up of mayors/county commissioners and they typically meet monthly; Mayors Partnership in SE Ohio has a roundtable you could brief.
- Depending on which counties are involved with the demonstration, groups like the Athens-Hocking County Transportation Advisory Committee (includes operations folks, etc.) should be utilized in outreach. Once you open the door to these folks, they can spread the word out organically.
- Engage advocates for across-the-board community communication, not just public officials. Should engage the public at large through radio, website, newspaper, and

social media to cover local communication. A 30–to 60-day advance communication blitz should be utilized up to deployment. Outreach efforts that are too fast or close to the deployment period could make the public concerned.

- Is there any summary documentation about the automated system, data points, technology and what this demonstration is trying to measure and can be shared?
- The law enforcement approach to ADS is going to be similar to the public approach. Officers are from the same rural Southeast Ohio area and will have the same questions as the public. Consider a marketing campaign.
- There is fear of the unknown; the American population in general may not welcome driverless vehicles but there are automated features that they desire (i.e. safety systems); that need general awareness for the public.
- There are digital messaging boards on the entry to Athens on US 33 and US 50.
- There's also a Local Comm Rural Action Plan that hosts a forum every couple of months (it's a structured way to gather feedback from traffic and fleet operators).
- The communications mechanism that's most effective in this district is social media; it's a method we use frequently in this area and suggest that for this case as well.
- On stakeholders, get with them early and often, especially lawmakers, public officials, and law enforcement. A regular e-news is one suggested method of communication.
- There could be value in doing public meetings and mailings as far in advance as possible.
- Be transparent and proactive. Let people know what's coming.
- People participating in the project may perceive we are viewing them as test rats, or, on the other hand, as leading edge depending on how they are introduced to the project.
- Matt is happy to help review talking points and provide input based on his expertise.
- The team should consider snail mail or social media as communication channels.
- Use digital messaging boards.
- There are also cameras at the 33/50 split on the north side near E. State St.
- Consider an on-site demonstration at the local high school – Vinton County has a K-12 campus west of McArthur. Jeff Kupko could come in and speak to the technology while it's in testing mode and help locals "touch and feel" the actuality.
- The Ohio University Airport is located on US 50 – could be a good idea to do a fly-in with elected and other officials for a demonstration; could have dignitaries ride in and do a site visit to allay fears (Director and the Governor could participate).
- Be conscious of concerns around the term "testing" – use the terminology "cutting edge" and get ahead of it; that said, say only what's needed. Honestly, many other road users may not know the test is going on if there are operators in the seat.

- Folks in southeastern Ohio and rural areas often feel “We want progress, not change”. Communication is different in urban versus rural vs a statewide audience delivery; think about wording, tone and voice for this audience as slightly different. Be sure to set expectations appropriately. Sell the sizzle, but don’t make promises that are unreal; if it’s not valuable, don’t say it.
- Be sure to keep the county engineers in Vinton and Athens engaged. Also, have township and village administration participate.
- I suggest preparing a crisis communications plan ahead of time.

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration

Testing Automated Trucks and Passenger Vehicles in Rural Ohio

Appendix

June 16, 2021

(updated with July 21, 2021 Focus Group information)

MURPHYepson

DriveOhio
The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio

End User Needs Appendix

June 16, 2021 (updated with July 21, 2021 Focus Group information)

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DriveOhio

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End User Needs Moderator's Interview Guide

May 3, 2021

CONTENTS CONFIRMED FOCUS GROUP DATES AND PURPOSE

Truck Automation only

- May 4, 9 - 10:30 - Logistics and Planning Professionals

Combined Truck/Passenger Vehicle Automation

- May 6, 3 – 4:30 PM - U.S. Department of Transportation
- May 10, 10:30 to Noon - SE Ohio Local Partners
- May 11, 9 - 10:30 – ODOT/DriveOhio #1
- May 12, 1 - 2:30 – ODOT/DriveOhio #2
- May 13, 9 - 10:30 - State Safety Officials

GOALS

- Build awareness and understanding of DriveOhio's automated driving systems project
- Seek stakeholder input to identify rural transportation challenges, passenger vehicle route options between McArthur and Athens, and end user needs/considerations for automated truck and passenger vehicle demonstrations/tests.
- Manage expectations that this is a safety data collection projects, but lessons learned could lead to improved mobility in rural areas and this collaboration could lead to other partnership opportunities

AGENDA, TIMING & QUESTIONS

A. Welcome, introductions and project overview (15 minutes)

- Moderator introduces staff on the call, including names and role
- Moderator recaps meeting goals and format
- Moderator introduces project with brief background (see slides)

B. Facilitated conversation on end-user needs and operational scenarios (70 minutes)

- Moderator asks questions, probing for more information and guiding conversation while also listening closely and allowing the attendees to inform the flow of the conversation.
- Moderator questions:
    1. This slide shows a number of issues related to passenger vehicle and truck automation. Let me review them and get your thoughts on each. (Discuss)
    2. Probe: What data/lessons learned would be most relevant to your organization?
    3. The objective of efforts like these is to collect safety data. Is there any information from the truck or passenger vehicle automation, any data, that would be helpful for your organization to have?
    4. What signage on the trucks, passenger vehicles or demonstration routes might be needed so that your staff or the public feels informed on what they're seeing?
    5. For the passenger vehicles, what roadways between McArthur and Athens would make good candidates for piloting these technologies? We want to test a variety of scenarios:
        a. Limited sight distances around curves or hills
        b. Limited sight distances due to heavy tree canopies
        c. Level and hilly terrain
        d. With/without pavement markings
        e. Where signage can be placed to alert the public about vehicle testing
        f. Where it won't interfere with law enforcement
    6. Are there any roadways, or roadway setups from your perspective that you don't see as a good fit for the automated passenger vehicle pilots?
    7. What time of day is best for testing to minimize interference with existing traffic or operations?
    8. From an enforcement perspective, what's necessary from your point of view for safe operation of these pilots?

9. What red flags does a demonstration like this set off for you? For example, we have heard that there may be concerns from the public on why trucks are following so closely. Do you agree with this concern and are there any others you have or you think the public would have?
10. What most excites you personally about the possibilities with innovative automated technologies?
11. Based on what we've discussed to this point, how do you envision interacting with the passenger vehicle automation pilot?
    a. What, if any, support would you want in order to interact properly with the passenger vehicle pilot?
    b. What, if any, support would you envision providing to support the passenger vehicle pilot?
12. Based on what we've discussed to this point, how do you envision interacting with the truck platooning automation pilot?
    a. What, if any, support would you want in order to interact properly with the trucking pilot?
    b. What, if any, support would you envision providing to support the trucking pilot?
13. When do you need to be informed about the deployment of the ADS demonstration? How early is it needed in order to bring all of your staff up to speed?
    a. What specifically would you want to know when it comes to that time?
    b. Who in particular is the best point of contact for us to touch base with?
14. What questions do you have for us?
15. For Truck Automation (see specific questions below)

C. Next steps (5 min)

D. Adjourn

Truck Automation Specific Questions

1. The perceived benefits of automated trucks and truck platooning involve fuel and operational savings plus reduced emissions that might, down the road, help you move freight more efficiently.
    a. How familiar are you with automated technology? Do you have trucks in your fleet equipped with advanced driver assistance systems (ADAS)?

b. As a shipper or carrier, how might automation affect your distribution strategies?
c. Specifically, would two automated trucks traveling together in a platoon integrate with your fleet or logistics business operations? Do you move enough freight to one location that platooning would help improve efficiency?
d. Do you see other benefits to pilots and eventual larger scale implementation of these technologies?

2. From your point of view what should the advanced driver assistance system do? What features or functions should it have? (see slide)
3. Data will be collected as the automated trucks operate on different types of roads.
   a. What types of roadways or factors of a roadway would be beneficial for you to have data on if you could choose where we do this pilot? (What data would be most applicable to <u>your</u> operations?)
   b. What information would be helpful to glean around operations in snow, ice, rain?
   c. What information would be helpful to glean around operations in rural areas that are hilly, steep or have limited internet connectivity?
   d. Are there benefits, and if so, what are they, of the system collecting data on approaching a crash scene or other special zone (e.g. work, tolls)?
   e. Three years from now, what other data would be useful to know before you consider implementing automated trucks into your operation?
4. How does time, day or regularity of the route affect your distribution of freight? Is there anything that would affect when it would be best to offer automation or more driver assistance?
5. Are most of the trucks you use equipped with Automatic Breaking Systems?
6. What kind of training would operators need? What might their reaction be to automation? (Which still requires an onboard operator)
7. What benefits would make it worth your while to consider using automated trucks in the future? What is most important to the business case?
8. Would you like to stay informed about the deployment of the ADAS truck field demonstration?
   a. What specifically would you want to know when it comes to that time?
   b. Who in particular is the best point of contact for us to touch base with?

Focus Group PowerPoint Presentation

DriveOhio

The Future of Smart Mobility

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Project

Testing Automated Trucks and Vans in Rural Ohio

May 2021

Ohio Department of Transportation

Agenda

- Who we are
- Why you’re here
- What ADS is and will demonstrate
- Our questions
- Your questions

Who We Are




Marie Keister
Murphy Epson
Stakeholder Engagement

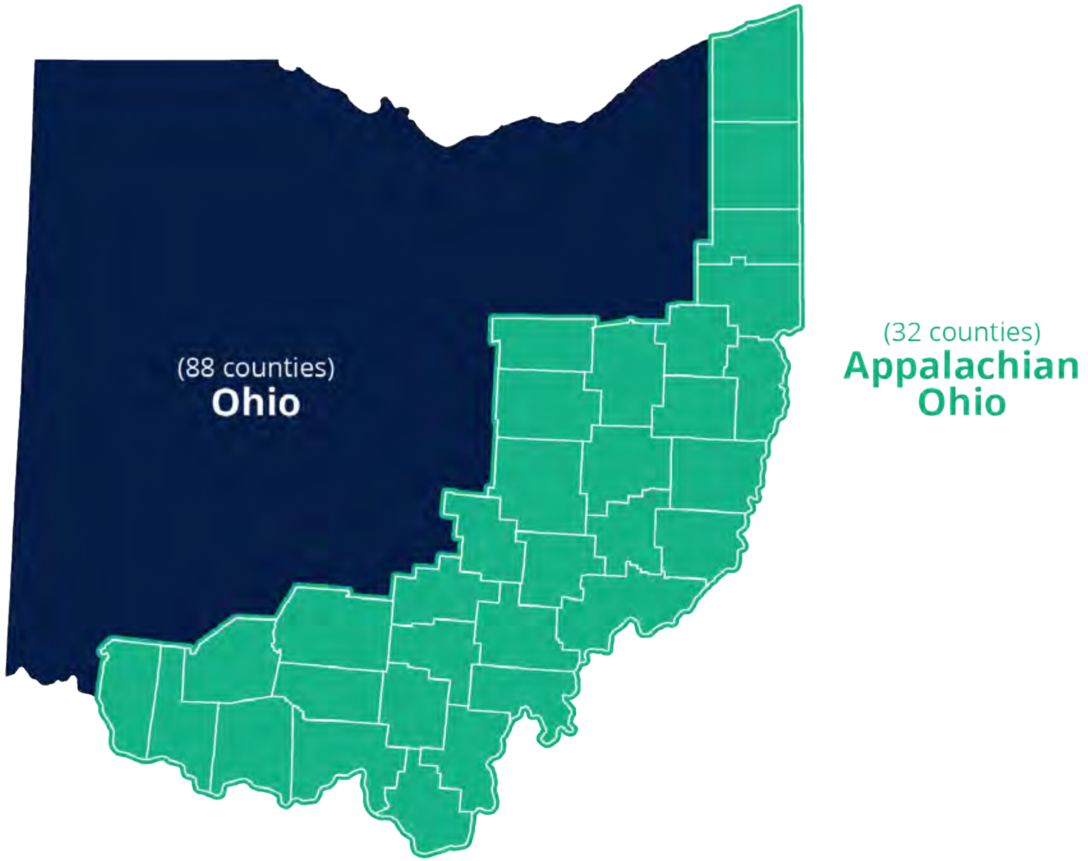
Mindy Justis
MurphyEpson
Stakeholder Engagement

Cynthia Jones
DriveOhio
Project Manager

Randy Butler
CDM Smith
Project Manager

Why You are Here

- To share your expertise and provide input on issues that will inform the development of the automated truck and van projects in rural Ohio



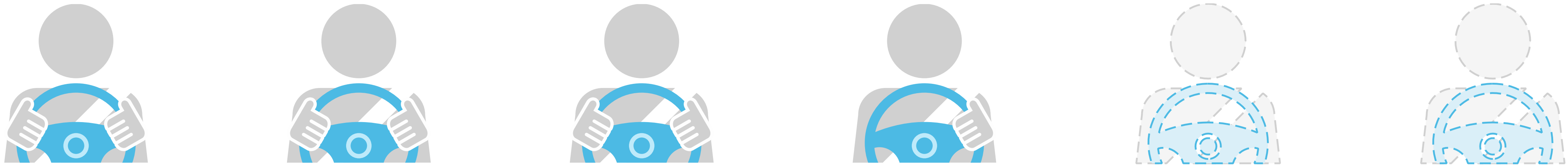
What the ADS Project is

Automated Driving Systems

- DriveOhio's automated driving systems (ADS) project will demonstrate how connected and automated semi trucks and vans could improve safety for drivers, passengers and other travelers in rural settings

Levels of Automation

Society of Automotive Engineers (SAE) Automation Levels



0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

ADS Focus Area (levels 2–4)

Source: NHTSA

Goal: Collect Data to Improve Safety

- Demonstration findings will help define technology needs and limitations as well as inform the safe scaling of future vehicle automation deployments in the U.S.

Funding Partners

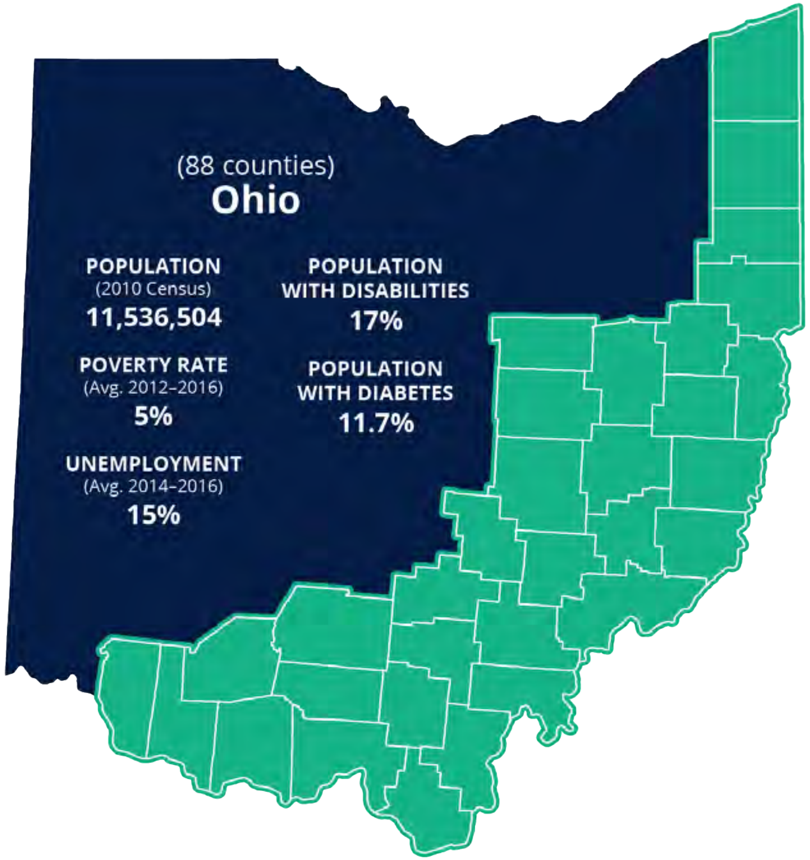
- USDOT $7.5 million grant to DriveOhio
  - Administrator: Federal Motor Carriers Safety Administration (FMCSA)
- Public/private funding partners
  - Transportation Research Center
  - JobsOhio
  - AutonomouStuff
  - University of Cincinnati
  - Bosch
  - Ohio University
- Consultant team: CDM Smith

Why Rural Ohio?

- A microcosm of the U.S.
- Most automation testing to date in urban areas
- 97% of land is rural nationwide[1]
- 19% of U.S. population in rural areas
- 54% of roadway fatalities occur on rural roadways (2.4x that of urban areas)[2]

1 American Community Survey 2013-2017
2 www.ncsl.org/research/transportation/traffic-safety-on-rural-roads.aspx

Mobility Challenges Affect Health and Economic Outcomes



(32 counties)
Appalachian Ohio[1]

POPULATION
(2010 Census)
2,042,040

POVERTY RATE
(Avg. 2012–2016)
6%

UNEMPLOYMENT
(Avg. 2014–2016)
18%

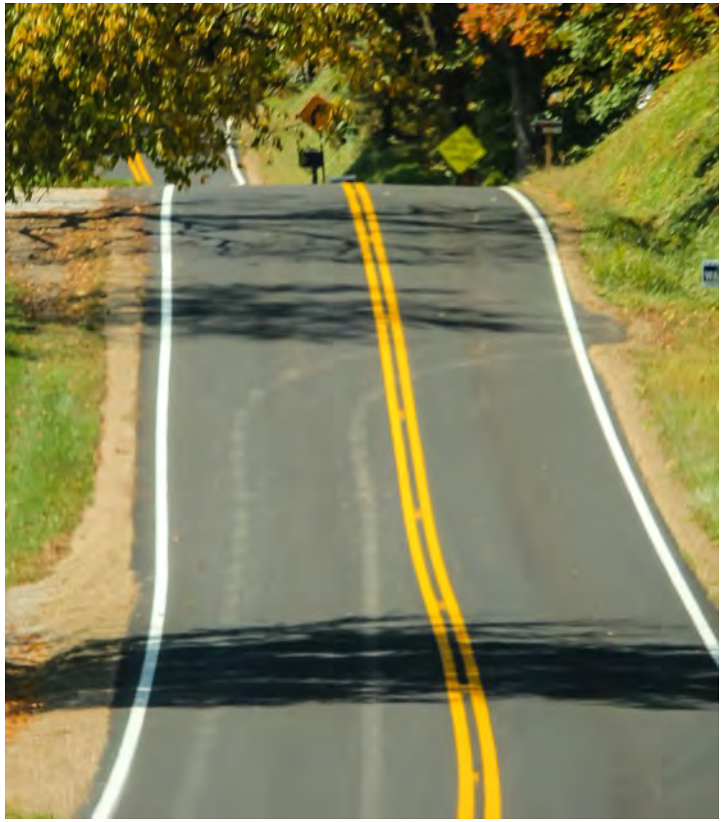
POPULATION WITH DISABILITIES
20%

POPULATION WITH DIABETES
13.1%

www.ohio.edu/medicine/di/needs-assessment.cfm: Appalachian Regional Commission Health Disparities in Appalachia, 2017; Rural Healthcare Access: Research Report, Appalachian Rural Health Institute, 2019.

Rural Challenges

Curvy, hilly terrain



Limited sight distances

Shaded tree canopies, limited internet

What will be Demonstrated

Truck Automation

- Will test partial, Level 2 automation technology for single tractor and platoon modes
- Includes wireless vehicle-to-vehicle (V2V) communication
- Engaged, professional driver at all times
- Will collect data on rural highways and various weather conditions

Level 2 automation can control both steering and accelerating/decelerating, but driver can take control at any time

Van Automation

- Will test partial, Level 3 automation technology in three Ford transit vans
- Includes AutonomouStuff tech and wireless vehicle-to-vehicle (V2V) communication
- Engaged, professional driver at all times
- Will collect data in various operating and environmental conditions, including limited visibility and work zones

Level 3 automation allows vans to make decisions for themselves, such as passing a slow-moving vehicle, but it still allows transfer of control to a human operator

Data Collection

- DriveOhio, TRC, UC and OU to collect and analyze:
  - Continuous stream data
  - Event data

Findings will inform policies that improve safety and benefit rural regions throughout the nation

Schedule

2020	2021				2022				2023				2024	Future
Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	

Planning & Systems Engineering

Automated Truck and Van Deployments (Iterative Rural Demonstrations)

Continuous Stream and Event Data Collection and Analytics (Ongoing Sharing with USDOT, FMCSA and Other Partners)

Continued Access to Data

Evaluation/ Reporting

End-User and Stakeholder Engagement (Ongoing)

Our Questions for You

Automated Vans

Van Demonstration Details

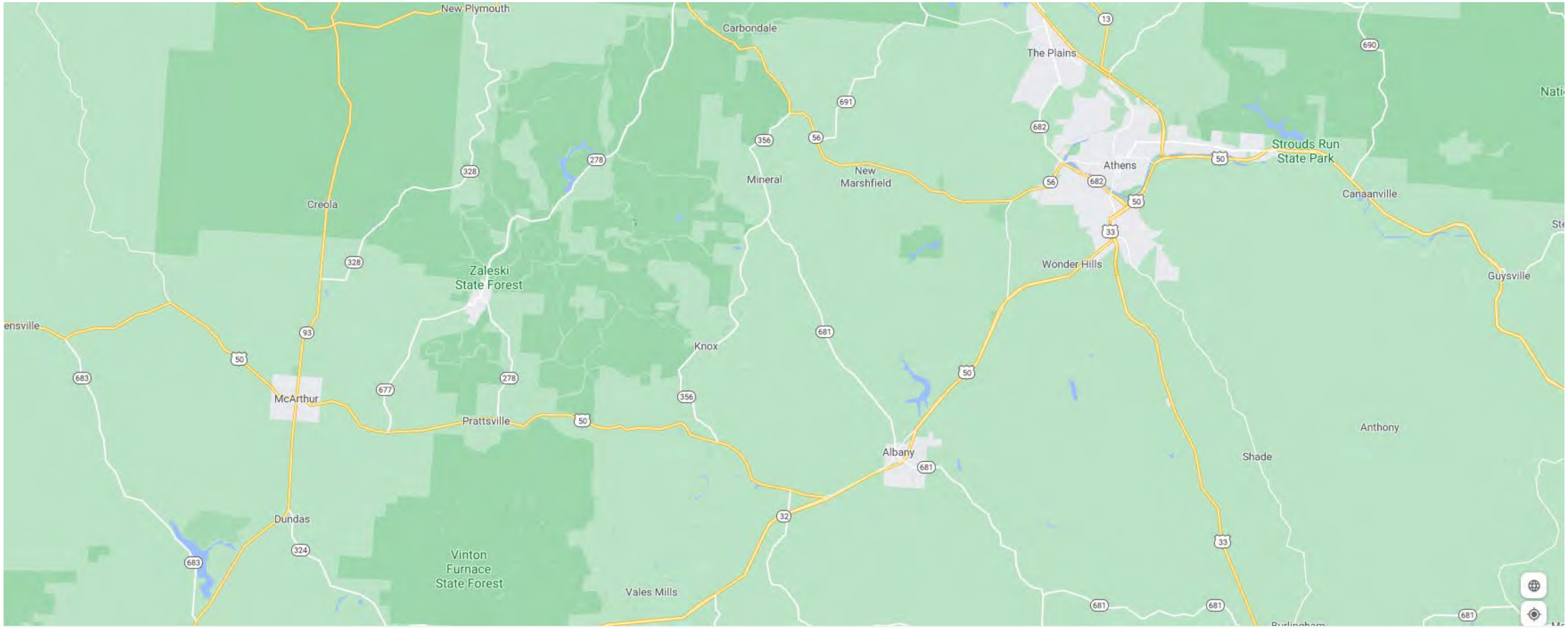
- 18-month field demonstration in rural Southeast Ohio (Athens and McArthur area)
- DriveOhio team will test Level 3 automation in three Ford vans
- Trained, professional driver behind the wheel at all times
- No passengers

- Specific routes to be determined by stakeholder feedback and test requirements
- Features to be tested include single vehicle automation and platooning operations

Van Automation Considerations

- Operations on various terrain, poor lane marking, various weather conditions
- Following distance
- Vehicle system and driver reaction to changing road conditions
- Interactions with other vehicles, animals and roadway infrastructure
- V2V roadside infrastructure to transmit info (poles with power
- Operational issues (e.g., law enforcement, public information)

Possible Routes



Our Questions for You

Automated Trucks

Truck Demonstration Details

- Goal: 18-month field demonstration in rural southern Ohio conducted by a host fleet in revenue service
- Use ODOT procurement process (RFI and RFP) to select a host fleet
- Host fleet to integrate two, Level 2 ADAS-equipped Navistar tractors into operations, in single tractor and/or 2-truck platooning modes

- The DriveOhio team will coordinate with the host fleet management, safety director and insurance carrier to:
  - Determine specific routes for platooning operations with host fleet
  - Communicate frequently
  - Train host fleet drivers

Truck Automation Considerations

- Rural, limited access highways
- Lane keeping capability
- Following distance
- Vehicle system reaction to changing road conditions
- Driver alerts
- Interactions with other vehicles and roadway infrastructure
- Load balancing
- Operational issues (e.g., law enforcement, public information, etc.)

Your Questions for Us

DriveOhio

The Future of Smart Mobility

Cynthia Jones, DriveOhio
614-256-0580 | cynthia.jones@dot.ohio.gov

drive.ohio.gov

OHIO DEPARTMENT OF TRANSPORTATION

Thank You

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Project

Testing Automated Trucks and Passenger Vehicles in Rural Ohio

Focus Group – SE Ohio Partners 2

July 2021

OHIO DEPARTMENT OF TRANSPORTATION

Agenda

- Welcome & Introductions
- DriveOhio
- Rural Ohio and ADS
- Questions and Discussion
- Next Steps

Welcome & Introductions

Who We Are

Marie Keister

Murphy Epson
Stakeholder Engagement

Cynthia Jones

DriveOhio
Project Manager

Randy Butler

CDM Smith
Project Manager

Why You are Here

- To share your expertise and provide input on issues that will inform the development of the automated truck and passenger vehicle projects in rural Southeast Ohio

DriveOhio

DriveOhio

- Ohio's portal to advancing smart mobility
- We're creating the transportation system of the 21st Century
- Together with our partners, we've developed the world's most advanced smart mobility ecosystem
- This includes connected, autonomous, electric and shared transportation….on the ground, in the air, everywhere

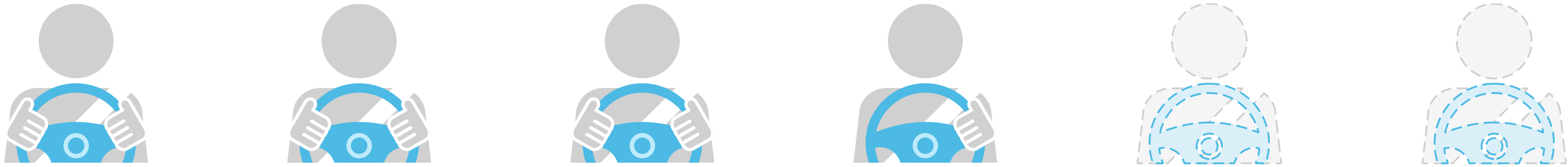
Rural Ohio and ADS

Automated Driving Systems

- DriveOhio's automated driving systems (ADS) project will demonstrate how **connected and automated semi trucks and passenger vehicles** could improve safety for drivers, passengers and other travelers in **rural settings**

Levels of Automation

Society of Automotive Engineers (SAE) Automation Levels



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Source: NHTSA

Rural ADS Focus Areas

Goal: Collect Data to Improve Safety

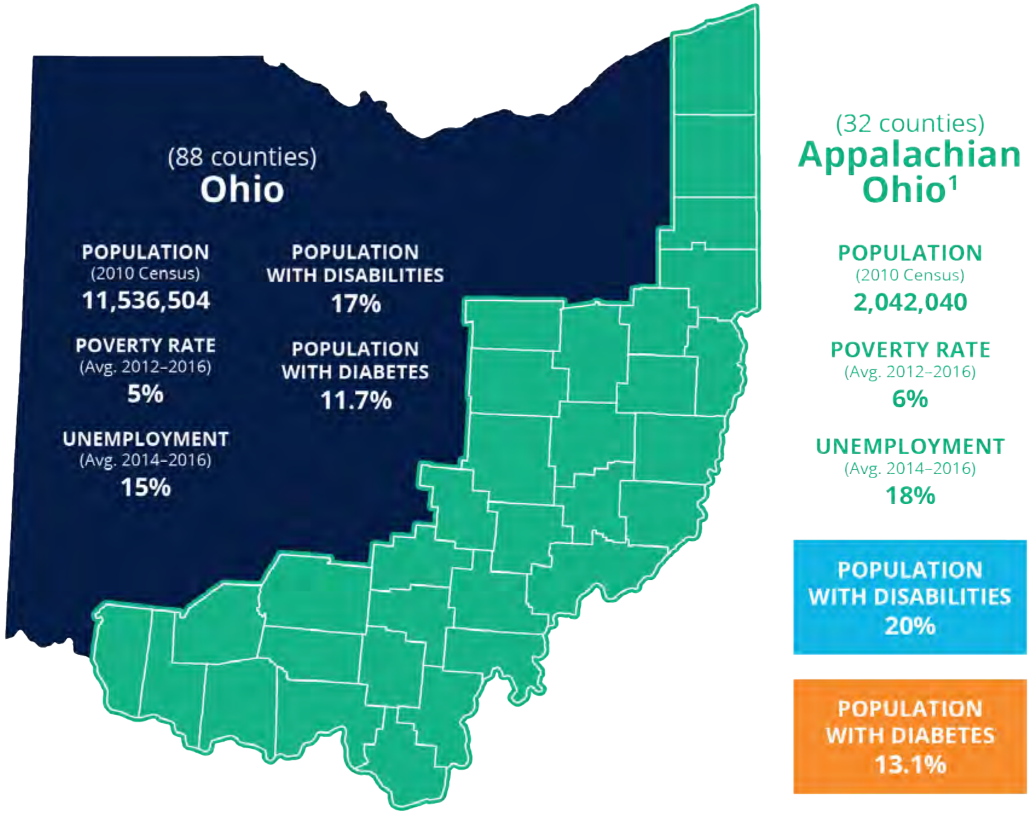
- Demonstration findings will help define technology needs and limitations as well as inform the safe scaling of future vehicle automation deployments in the U.S.
- End users:
  - Rule-makers
  - Policymakers
  - Transportation experts
  - Researchers

Funding Partners

- USDOT $7.5 million grant to DriveOhio
  - Administrator: Federal Motor Carriers Safety Administration (FMCSA)
- Public/private funding partners
  - Transportation Research Center
  - JobsOhio
  - AutonomouStuff
  - University of Cincinnati
  - Bosch
  - Ohio University
- Consultant team: CDM Smith

Mobility Challenges Affect Health and Economic Outcomes

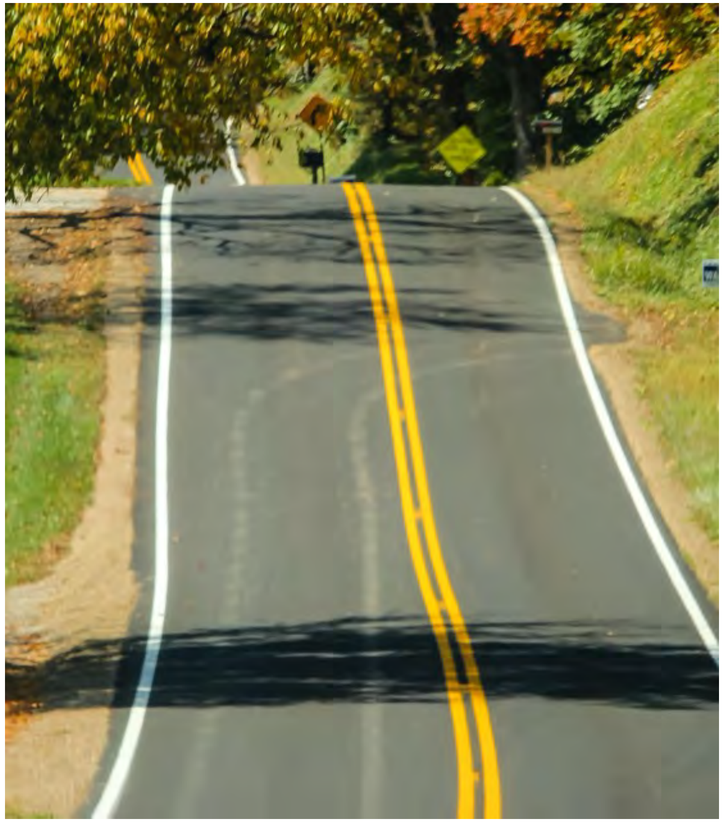
- 97% of land is rural nationwide[1]
- 19% of U.S. population in rural areas
- 54% of roadway fatalities occur on rural roadways (2.4x urban areas)[2]
- Mobility hurdles affect health and job outcomes[3]
- Most automation testing to date is in urban areas



1 American Community Survey 2013-2017
2 www.ncsl.org/research/transportation/traffic-safety-on-rural-roads.aspx
3 www.ohio.edu/medicine/di/needs-assessment.cfm: Appalachian Regional Commission Health Disparities in Appalachia, 2017; Rural Healthcare Access: Research Report, Appalachian Rural Health Institute, 2019.

Rural Challenges

Curvy, hilly terrain



Limited sight distances

Shaded tree canopies, limited internet

Truck Automation

- Will test partial, Level 2 automation technology for single tractor and platoon modes
- Includes wireless vehicle-to-vehicle (V2V) communication
- Engaged, professional driver at all times
- Will collect data on rural highways and various weather conditions

Level 2 automation can control both steering and accelerating/decelerating, but driver can take control at any time

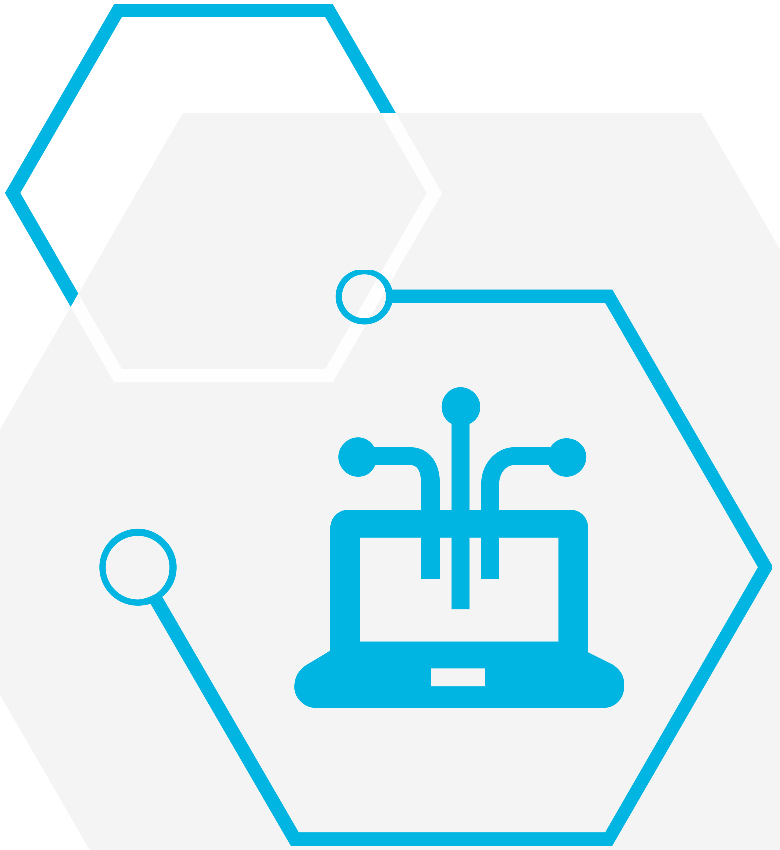
Vehicle Automation

- Will test partial, Level 3 automation technology in passenger vehicles
- Includes AutonomouStuff tech and wireless vehicle-to-vehicle (V2V) communication
- Engaged, professional driver at all times
- Will collect data in various operating and environmental conditions, including limited visibility and work zones

Level 3 automation allows vans to make decisions for themselves, such as passing a slow-moving vehicle, but it still allows transfer of control to a human operator

Data Collection

- DriveOhio, TRC, OU and UC to collect and analyze:
  - Continuous stream data
  - Event data



Findings will inform policies that improve safety and benefit rural regions throughout the nation

Passenger Vehicle Discussion

Passenger Vehicle Considerations

- 18-month field demonstration in rural Southeast Ohio (Athens and McArthur area) – Start Nov. 2022
- No passengers
- In automation mode most of the time but track when engage/disengage functions occur

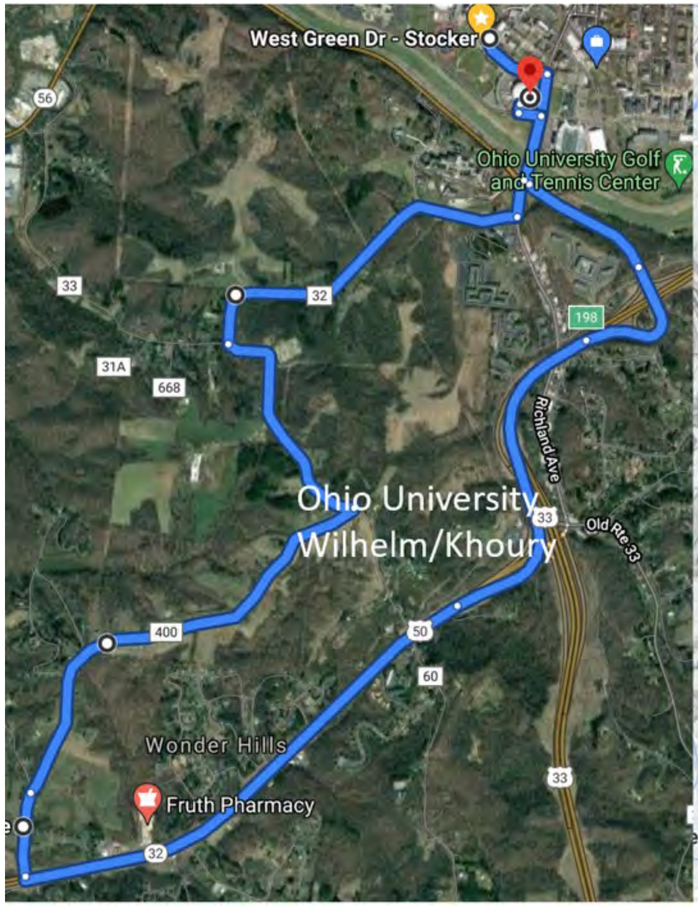
- Route/testing parameters:
  - Hilly terrain
  - Poor, uneven terrain
  - Winding roads
  - Limited sight distances
  - Dense tree canopies
  - Unmarked pavement (or various)
  - Limited cell/GPS reception
  - Interactions with animals, other vehicles

Possible Routes

Calibration Loops

- 2- or 4-lane route with unmarked roads
- Short trips < 20 minutes
- Start/stop at OU Engineering Building

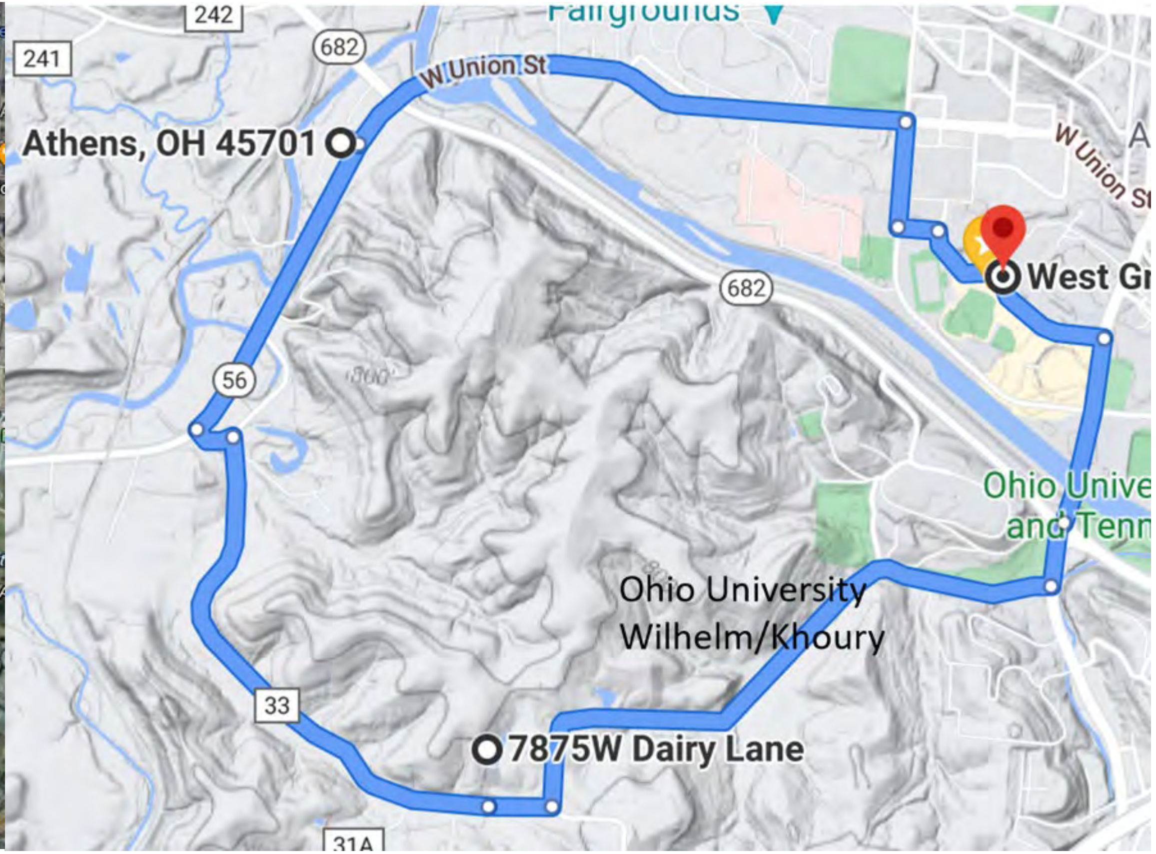
Calibration Loop Option 1 – 18 min./8.2 mi.



Township road

State route

Calibration Loop Option 2 – 15 min./5.1 mi.



Athens to McArthur (51 mi.)

Alt. parts unmarked

2 lane marked road – max 45 mph – windy/elevation changes

2 lane marked road – max 55 mph

Start at OU-Engineering

Outreach Considerations

- Stakeholder engagement
- Law enforcement
- Public education
- The long-term business case

Level 3 automation allows vehicles to make decisions for themselves, such as passing a slow-moving vehicle, but it still allows transfer of control to a human operator

Truck Discussion

Truck Demonstration Considerations

- Goal: 18-month field demonstration in rural southern Ohio conducted by a host fleet in revenue service
- Use ODOT procurement process (RFI and RFP) to select a host fleet
- Host fleet to integrate two, Level 2 ADAS-equipped Navistar tractors into operations, in single tractor and/or 2-truck platooning modes
- DriveOhio will coordinate with the host fleet management, safety director and insurance carrier to:
  - Determine specific routes for platooning operations with host fleet
  - Communicate frequently
  - Train host fleet drivers

Outreach Considerations

- Stakeholder engagement
- Law enforcement
- Public education
- The long-term business case

Level 2 automation can control both steering and accelerating/decelerating, but driver can take control at any time

Next Steps

Schedule

2020	2021				2022				2023				2024	Future
Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	
		Planning & Systems Engineering					Automated Truck and Van Deployments (Iterative Rural Demonstrations)							
							Continuous Stream and Event Data Collection and Analytics (Ongoing Sharing with USDOT, FMCSA and Other Partners)							Continued Access to Data
												Evaluation/ Reporting		
End-User and Stakeholder Engagement (Ongoing)														

DriveOhio

The Future of Smart Mobility

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drive.ohio.gov

Ohio Department of Transportation

Thank You

Focus Group Meeting Summaries

DriveOhio

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DriveOhio
The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Group – Logistics and Planning Professionals

May 4, 2021 | 9:00 AM-10:30 AM | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- Tom Balzer, Ohio Tucking Association
- Zakee Bashir, Columbus Region Logistics Council
- Mark Locker, ODOT (Freight and Maritime Operations)

- *Randy Butler, CDM Smith*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Marie Keister, MurphyEpson (Moderator)*
- *Mindy Justis, MurphyEpson*
- *Ben Ritchey, CDM Smith*
- *Nick Hegemier, DriveOhio*

FOCUS GROUP SUMMARY

Marie Keister kicked off the focus group with a welcome, and then provided an overview of the project parameters. This included project definitions, goals, list of funding partners, challenges, a schedule and truck details. The content was purposefully geared toward the trucking automation portion of the project due to the specialized group of attendees who focus on this subject matter. Following the presentation, Marie facilitated a series of questions to the three meeting participants. During the conversation, Ben Ritchey and Randy Butler also asked questions of participants and provided responses to technical questions asked by participants. A summary of comments, questions and discussion is highlighted below. Once the user needs were collected the focus group was adjourned.

USER NEEDS INPUT

The following is a summary of user needs collected through comments, responses to questions and focus group discussion.

What other things would you like to know about with automation or what have we missed?

Zakee Bashir

- I'm interested in who will publicly take a leadership role as the owner of the automation conversation, i.e., who is doing what first?

Tom Balzer

- A market situation and tech reality are even two different things; it may be tech feasible but there may be no business case for it.
- In industry, there are questions on whether competitors could platoon off one another (leaching).
    - Overall, there is a lot of industry chatter around how many trucks maximum are allowed to platoon at one time.

Would truck automation data be helpful to the organizations you work with/industry you represent?

Tom Balzer

- Workforce: There is a fear that exists in trucking of operating large vehicles and that is a barrier to some people choosing to become "truckers" – to find the needed talent at a time when there is a driver shortage, this has the potential to bring in additional people.
- Noted a concern about platooning not being practical in rural settings because two full trucks aren't stopping in the same place; suggested doing fake scenarios at TRC rather than in revenue settings (freight could be faked for weight in the truck).

Mark Locker

- I hear that additional sensors are helpful for operators; they help with maneuverability.
- This tech also tells ODOT where infrastructure can be improved; helps inform traffic managers.

Zakee Bashir

- Could one goal of the demonstration simply be exposing the industry to the technology realities?

Now that you understand a little more about what we will be testing, how might you use this technology once it's available to the public? What would be of most interest to you?

Mark Locker

- Workforce development is a really big deal – freight matters in Ohio. Mark wondered if there was an opportunity for a talent fair that also helps bring about excitement in younger people (a larger talent pool).

Zakee Bashir

- Agreed with this sentiment and suggested that trade schools might get excited about an opportunity to engage.
- Get tech/fleets together for a career day.

Tom Balzer

- Tom noted that with the general public large machinery and manual transmission understanding is more limited now than ever and that can be a real barrier to obtaining new drivers (especially at a time when the industry is already facing a driver shortage and a number of drivers are expected to retire soon); one potential benefit of autonomous technologies is that it could expand the net of interested talent; there are truckers who are used to tight corners and congestion, but most are not.

Talking more about finding a host fleet, do you see any major opportunities or challenges in finding a fleet partner?

Tom Balzer

- It will be no problem to find a host fleet, but the travel area is important. Most importantly, it has to make business sense for the fleet operator to participate.
- May be most advantageous for time critical and high quantity deliveries such as fuel haulers or animal food haulers.
- Tom is concerned that the technology has so many limitations that it's basically just adaptive cruise control on steroids; he feels there are real weaknesses to platooning and very rare cases where the operation makes sense.

Zakee Bashir

- Suggested a ride along at the TRC test track or during the demonstration if possible to help professionals and electeds understand where the technology is right now.

Tom Balzer

- If a test case is done rather than on an actual road, bricks of concrete can be loaded in to simulate cargo weight without chancing it with live cargo; in fact, truckers will often keep ballasts full of water in empty trailers to add into their trailers if they are light and it's windy out.
- It's the cargo, not the truck that matters from a cost perspective; for example, a truck of chickens is valued at 80k.

Do you have any thoughts on safety implications?

Tom Balzer

- For a single truck, lane keeping is already fairly common on trucks; some of the bells and whistles are already on the newer trucks so the question is what's the value add of all of these together? There will be people who wonder how this is any better because it can be really clunky at times.

What are the biggest challenges?

Tom Balzer

- From a policy point of view, there's a concern that autonomy will take away existing jobs; there's also a concern about the safety of other road users (especially if they attempt to cut in between two platooning trucks).
- Cargo insurance is substantive so that may be an element of the demonstration that presents a challenge.

What other issues do you foresee?

Tom Balzer

- The goal here should be more about what the business case for automation is – a cost/benefit analysis as well as the safety and research.

Mark Locker

- No others; this is all a really great conversation and I'm glad we're having it.

What questions do you have for us?

Mark Locker

- What will the signage and/or communications be to drivers and the public? This is important.

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Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Group – U.S. Department of Transportation

May 6, 2021 | 3:00-4:30 PM | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- John Harding, FHWA
- Hyungjun Park, FHWA
- Chris Flanigan, FMCSA
- Thomas Kelley, FMCSA
- Jeff Loftus, FMCSA
- Dan Meyer, FMCSA
- Greg Piland, FMCSA
- Brian Routhier, FMCSA
- Danyell Diggs, FTA
- Steve Mortensen, FTA

- *Randy Butler, CDM Smith*
- *Ben Ritchey, CDM Smith*
- *Roger Schiller, CDM Smith*
- *Ken Troupe, CDM Smith*
- *Nick Hegemier, DriveOhio*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Andrew Wallace, DriveOhio*
- *Mindy Justis, MurphyEpson*
- *Marie Keister, MurphyEpson (Moderator)*

FOCUS GROUP SUMMARY

After introductions, Marie Keister walked through several slides to provide an overview of Ohio's Automated Driving Systems (ADS) project. She then outlined the details of each project and sought input from participants. Cynthia Jones also asked questions, while the

CDM Smith team provided responses to technical questions. A detailed summary of questions and comments is outlined below. Once the user needs were collected the focus group was adjourned.

USER NEEDS INPUT

The following is a summary of user needs collected through comments, responses to questions and focus group discussion.

We would like to get your thoughts on Passenger Vehicle Automation issues?

Jeff Loftus

- I'm worried about the Level 3 automation. Aviation studies show it takes 10 seconds for a human to react and take over an automated function. We're advising that when we are asking drivers to monitor automated functions, we need to keep driving time durations short so we don't have driver fatigue or boredom, which may slow reaction time.
- Check the recent research on this -- see SAE recommendations.
- ***Randy Butler:***
    - *We're following Carma for their counsel on precedents. We will also discuss our proposed driver operations with the IRB.*
- ***Cynthia Jones:***
    - *We will ask our risk management team to conduct a scan for the most recent research.*

Steve Mortensen

- What is the rationale behind platooning passenger vehicles in a rural environment?
- ***Randy Butler:***
    - *We are following Carma open-source data to gain an understanding of whether this makes sense to do. Iowa's project will have a safety driver and a co-pilot to monitor and collect data. Their AV provider is the same as ours, AutonomouStuff. They also built test trucks for FHWA.*

John Harding

- Regarding the mapping, you'll need to get feedback from AutonomouStuff on operational parameters for routing.

Jeff Loftus

- Bosch also has good input on vehicle routing requirements along with AutonomouStuff. We will want to review and weigh in on your test plans. We want your plans to complement what the other ADS projects are doing, and we want to encourage collaboration.

Danyell Diggs

- A Contra Costa County hospital system is doing a wheelchair-lift equipped shuttle service using Level 3 and 4 automation and traveling up to 50 mph. It is one of three projects in Contra Costa County - all of them kicked off in April.

Jeff Loftus

- I am so glad you are engaging local officials. Manufacturers are very interested in understanding the operational scenarios -- for example, concerns from local law enforcement, emergency responders, local weigh stations, etc.
- Does there need to be a local law enforcement plan?
- What do safety officials need to trust operations and testing on public roads?
- Also ask transit agencies how their passengers would feel, and how about interactions with pedestrians and bicyclists?
- How does the vehicle communicate its intent to other road users - and vulnerable road users? This input will be very helpful across the U.S.

Danyell Diggs

- Also ask EMS these same questions.

Steve Mortensen

- Will there be passengers? (Only the professional driver and potentially a member of the project team.)
- My only comment is that all FTA (public transit) operations need to be ADA-compliant, but you won't need that here. The Western Reserve Transit Authority project in Youngstown is looking at automated functions for ADA services.
- ***Cynthia Jones:***
  - *We will also test Paralyft's automated/robotic wheel-chair lifts. We are also a supporter of the Youngtown project. (FTA liked the test idea and appreciated the collaboration across Ohio.)*

We would like to get your thoughts on Truck Automation issues?

Ben explained that the trucks will be leased from Navistar, and Bosch will do the uplifting to ADAS with software and other technology.

General Comment

- Sounds good. Think about what license plates they'll use or what type of permitting will be needed. We've discovered this is a sticky issue. Get the DMV and DPS involved early.
- ***Cynthia Jones:***
  - *We are coordinating with the Ohio Bureau of Motor Vehicles and State Patrol, and we will also work with Public Utilities Commission of Ohio (PUCO) as needed for licensing. However, we're hopeful that the host fleet will be able to use its own licenses/permits so we won't have to deal with this issue.*

Hyungjun Park

- We are working with Roly's Trucking, which is based in California, for a demonstration there. They purchased trucks and we leased the trucks from them. They are doing a 1,400-mile test route from California to New Mexico to Texas. My advice is to involve the state police as soon as possible, and keep them involved early and often, even if you don't need specific input. In California, they asked that we put an indicator light on the trucks when they are in platooning mode.

- Also, confirm the laws on following distance in Ohio and get a waiver if you need it. (Cynthia noted they are already looking into this.) Hyungjun noted that the state patrol will know all about these types of issues and will raise them.
- Regarding insurance concerns, Roly's has been so supportive. CPASS meets with them every other week, and they learn so much. I would advise you to do the same. Insurance is not an issue because they are using their own trucks. We did have to train their drivers. In two or three months I can share all the training documents and materials with you. They start operating at the end of this year, so I can send all lessons learned with you. This should be a big help since you won't start until about a year later.

Question

- Do you have freight density to justify platooning, or the distance needed between two trucks yet?
- ***Ben Ritchey:***
    - *Bosch is working through those details, but a lot will depend on whether we are able to get a host fleet.*

Greg Piland

- See the NHTSA report on braking distance and its functional safety study in Level 2 automation mode. It walks developers through the standards. (Sent link). TRC has also done this type of work.
- For truck platooning, you might ask the fleet operator what systems they have to measure fuel savings, productivity savings and the safety benefits for the second driver. Also ask them how they communicate. Talk through collecting data on these benefit areas.
- Also consider how to counter boredom and complacency. It would be very helpful to us to get this kind of operational data.
- ***Randy Butler:***
    - *Regarding the second driver, should we put a camera onboard to monitor the driver? Also, the NOFO didn't mention wanting operations data so we just cut that out of our work, but we can put it back in.*

Hyungjun Park

- What is your grant not going to answer that we could address, and can your budget handle it?
- Driver fatigue and the operation value to the fleet is important to understand. That will help the trucking industry understand the return on investment, and whether this is worth the investment. That's what we are curious about. (CDM Smith has a memo on FHWA measures.)
- Also, we have done some video-based sensors of the brainwaves of drivers. It's okay to duplicate what we are doing in the California/NM/Texas study, though -- more data is good. We're still figuring out what we don't know yet.
- Also, see the Virginia Tech cookbook on how to integrate AV trucks into a regular fleet. Ask the fleet host what their maintenance concerns might be.
- Freightliner and Bendix are about to manufacture Level 2 trucks, but they won't be available until 2021. Platooning is not yet in production.

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Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Group – SE Ohio Local Partners

May 10, 2021 | 10:30 AM-Noon | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- Sam Wallace, Buckeye Hills Regional Council
- Brett Boothe, Gallia County Engineer
- Bret Allphin, SIXMO City Services

- *Randy Butler, CDM Smith*
- *Nick Hoffman, MurphyEpson*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Mindy Justis, MurphyEpson (Moderator)*
- *Jeff Kupko, Michael Baker International*
- *Ben Ritchey, CDM Smith*
- *Roger Schiller, CDM Smith*
- *Andrew Wallace, DriveOhio*

FOCUS GROUP SUMMARY

Mindy Justis kicked off the focus group with a welcome and dove into the presentation. A brief overview was given about Ohio's Automated Driving Systems (ADS) project. This included project definitions, goals, list of funding partners, challenges, a schedule, truck and passenger vehicle details and possible routes. Following the presentation Mindy facilitated a series of questions to the three meeting participants. Cynthia Jones also asked questions, while Randy Butler and Roger Schiller provided responses to technical questions. A summary of comments, questions and discussion is highlighted below. Once the user needs were collected the focus group was adjourned.

USER NEEDS INPUT

The following is a summary of user needs collected through comments, responses to questions and focus group discussion.

What other things would you like to know about with automation or what have we missed?

Brett Boothe

- Concerned about wearing surfaces of roadway and future uses of these ADS technologies.
  - For example: there is a booming log cabin business with homes being sold across the county and these are being built along roadsides and materials are being delivered by an influx of trucks (load after load).
  - Is the ADS project/team looking into this?
- Routes like US 35 already have high truck traffic; truck stops are at capacity and trucks are parked on the sides of the roads (overnight) all along US 35.
- Another concern is that smaller roads don't always have edge lines.
- There is a large Amish population in Gallia County which have different transportation needs and concerns.
- I know the team is looking at testing on US 33, but US 35 has a higher percent of truck traffic than I-70, east of Columbus (When WV section is constructed there will be a 4-lane highway from to Charleston).
  - This may be a route to look at for ADS?
- Noted that county roads lane width change (smaller etc. than state routes)
- ***Roger Schiller:***
  - *Confirmed Brett's comments were all in regard to the Truck Automation and not the Passenger Vehicle Automation.*
  - *Noted the ADS team has not looked at the wearing of road surfaces but instead Platooning Technology is using radar to maintain distance and detect other vehicles.*
  - *Lane markings could come into play where vehicles wouldn't be able to operate.*
- ***Randy Butler:***
  - *Commented that meetings/workshops are being held to discuss pavement evaluation along with mapping etc.*
  - *Reminder that we're only platooning two trucks/trailers.*

What do you see as the highest crash locations/intersections or difficult areas?

Brett Boothe

- Gallia County has completed an extensive safety study for the entire county, including villages and cities; doesn't have data for Athens or Vinton County etc.

Now that you understand a little more about what we will be testing, how might you use this technology once it's available to the public? What would be of most interest to you?

Sam Wallace

- The most exciting aspects is advancing mobility options in southeast Ohio rural areas.
- There are mobility barriers to this rural population including aged, at-risk, substance abuse recovery and disabled.
- If there are more transportation options to get transportation service out to these folks that doesn't require a lot of overhead (drivers, etc.) this would allow for more opportunities.
- Overall economic opportunities for rural areas.

Bret Allphin

- Optimism for next thing; need to realize the number of folks currently not utilizing our transportation networks in rural communities – excited for future uses in rural Ohio.
- Not many options for those that need transportation on demand etc. (at random times during the day, for work or appointments etc.
- Understand these opportunities are down the road but not that far off (less than 50 years).

What are your thoughts/perspective about 3-4 passenger vehicles driving in close proximity to each other? Does that disrupt traffic? What is the public perception?

Sam Wallace

- I would think 3-4 passenger vehicles platooning close together would be disruptive; depends where this occurs and what routes they are traveling on? Where does the deployment take place?
- If a pooling of automated vehicles were in close proximity at one of the 10 most dangerous intersections, that might be a bit much, but if they are traveling on straighter state routes this probably wouldn't be a problem.

Bret Allphin

- Automation is not distracting as long as there are "drivers". Once we start talking about vehicles without people/operators, that becomes more alarming. I don't think 3-4 passenger vehicles is going to tip over the apple cart from the public's perspective.

Comment

Bret Allphin

- ADS testing should consider wildlife interaction with autonomous testing as there are no countermeasures when interacting with a wild animal. Would not leave this off your list of things to consider.
- When collecting data, note: Buckeye Hills takes out animal crash strikes of data, as there's nothing they can do for countermeasures for the public.

Would either passenger vehicles or truck automation data be helpful to your organization?

Sam Wallace

- Both passenger vehicles and truck data would be helpful for many logistics organizations.

Bret Allphin

- Truck information will be helpful to local logistics/freight companies.
- This technology will be a hard sell for traditional companies to think about using, so the earlier its publicized the better.

Do you have any thoughts on safety implications?

No response.

When do you need to know information about the study?

Sam Wallace

- Prior to testing, 30-60 day alert and reinforced is needed to get word out

Bret Allphin

- There is a cool factor to this effort and don't want to see it lost, the sooner the better and as many public outreach opportunities the better.
- This will allow for public opportunities to let people learn, see and touch it.
- It a great opportunity for the SE Ohio region as most testing is in larger cities.

Who is a good audience for these messages?

Bret Allphin

- ADS public outreach contacts include: Public officials; county engineers; Transportation managers like Sam at Buckeye Hills; and then arming those folks/advocates, the finally distilled down to public.

Is there a regular forum/cadence for interacting with SE Ohio public officials? (Cynthia Jones)

Bret Allphin

- Additional contacts include: Sam Wallace (Buckeye Hills); Brett Boothe (Gallia County) is in the Ohio Valley Regional Commission, Buckeye Hills, OMEGA, Eastgate and Youngstown and their boards are made up of mayors/county commissioners and they typically meet monthly; Mayors partnership in SE Ohio (roundtable opportunity); Either Sam or I can provide contacts/introduction to these officials.

Sam Wallace

- Depending on which counties you want to reach out to there are groups like the Athens-Hocking County Transportation Advisory Committee (includes operations folks etc.). Once you open the door to these folks, they can spread the word out organically.

What are the biggest challenges?

Sam Wallace

- Need to consider broadband, connectivity, topography blocking signals (line to line communication), lane markings, mapping data may come into play (roadway mapping/information isn't very robust in rural areas in US – roadway length, width, speed etc.).

Brett Boothe

- Need to consider issues with roadway curves, local/county roads, road widths (different road widths/are all over the board), Wi-Fi connection (on Gallia 40% have zero cell service/signals).

Any thoughts on high collision/traffic areas?

Brett Boothe

- When looking at dangerous roadway locations, my guess is State Routes near traffic signals. This depends; need to look at each county's crash statistics.

When do you think the right time to engage public in the media? The last article, to knowledge, was in the Athens Messenger on April 16, 2019? Or should we stick with the public officials? (Cynthia Jones)

Sam Wallace

- Advocates for across-the-board community communication, not just public officials. Should engage public at-large through radio, website, newspaper, social media to cover local communication. When? 30-60 advance communication blitz up to deployment. Doing too fast/close to deployment period could make the public concerned.

What other issues do you foresee?

Brett Boothe

- The one thing about SE Ohio is that we have lots of hills/curvy terrain and an unprecedented amount of guardrails, but we still have issues with many places that don't have guardrails including township/local roads – some are stone roads; advisory speeds with curves is not always posted.
- Are you considering winter issues – ice/snow?
- What if a tree comes down in the road?
- Flooding events could be an issue (folks that drive through high water – may be assessed fees for emergencies service if they get stuck).

What questions do you have for us?

Sam Wallace

- Is there any summary documentation about the automated system, data points, technology and what this demonstration is trying to measure?
- ***Randy Butler:***
    - *As part of the process we are creating a concept of operations, scenarios of how the system will operate, testing, and a performance plan etc. These will be available in the first quarter of 2022 – as they are approved, they can be sent out.*

Brett Boothe

- Is it critical that the study pick up/need the road centerline to operate?
- ***Randy Butler:***

- *Yes, the system in Level 2 will pick-up center lines, but if center lines aren't there the system will revert back to Level 1.*
- *Automation of vehicle will revert back to lower automation level; operator would be driving truck (may no automation); also looking at lower level of automation in bad weather/detecting work zones.*

How far off the roadway you've mapped? And was it raw or post-processed data? (Jeff Kupko)

Brett Boothe

- Gallia County has conducted 4K video (360 degrees) on all roads (plus lidar); Note: not every county may have this.
- On road surfaces, Gallia County used Ultra 4K to come up with pavement condition ratings and other data. After data was processed, we can measure right-of-way mapping within 1 centimeter of accuracy. Also flew 3-inch aerials.

- I already know Cynthia and CDM Smith and glad to serve on any expert panels.

Jeff Loftus

- We'd like to see all eight grants learn from each other. We are very excited this is all getting started.
- ***Cynthia Jones:***
    - *Omar from Iowa has already proposed an AV breakout session at the Automated Roadway Conference on July 12 -15.*
- That's great. We'd love to see all the grants in a chart that summarizes the projects, which ones Carma is on, etc.

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Groups – ODOT Staff

May 11, 2021 | 9:00-10:30 AM | Zoom Meeting
May 12, 2021 | 1:00-2:30 PM | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- Matt Bruning, ODOT
- Alan Craig, ODOT District 10
- Eric Davis, ODOT District 10
- Dominic Delco, ODOT
- Chuck Dyer, ODOT
- Sarah El-Dabaja, ODOT District 10
- Erica Hawkins, ODOT
- Jamie Hendershot, ODOT District 10
- John MacAdam, ODOT
- Erin McBride, ODOT
- Mike McNeil, ODOT
- Darla Miller, ODOT District 10
- Scott Phinney, ODOT
- Ashley Rittenhouse, ODOT District 10
- Todd Seiter, ODOT
- David Stiffler, ODOT District 10
- *Rich Granger, DriveOhio*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Mindy Justis, MurphyEpson*
- *Marie Keister, MurphyEpson (Moderator)*
- *Jeff Kupko, Michael Baker International*
- *Ben Ritchey, CDM Smith*
- *Roger Schiller, CDM Smith*
- *Andrew Wallace, DriveOhio*

FOCUS GROUP SUMMARY

Marie Keister started each of the two focus groups with an overview presentation and then the remainder of the session was formatted as a facilitated conversation. The beginning overview included what the project is, what will be demonstrated, project definitions, goals, a list of funding partners, challenges, a schedule, truck and van details and possible routes.

Following the presentation, Marie facilitated a series of questions to each set of meeting participants. Due to the volume of relevant ODOT staff stakeholders, attendees were invited to two sessions and able to select between the two for the timing that fit best for them. Content presented at each of the two sessions was identical. A summary of comments, questions and discussion is highlighted below. Once the user needs were collected the focus groups were adjourned.

USER NEEDS INPUT

The following is a summary of user needs collected through comments, responses to questions and focus group discussion.

Do you have any thoughts about locations to consider or avoid for the automated van portion of the project?

Allan Craig

- Test grades between State Street and US50 on US33.
- Navigation that truckers use often lead them to dead ends.
- Baker Road at US50 between Athens - this area is narrow and windy with no pavement markings.
- US 50 East to US 33 East.

Scott Phinney

- This area is part of the state's strategic freight network.
- Concerned about how the automated vans will operate with freight traffic that regularly travel these roads.
- Suggested US 33 and US 50 (between 33 and 32), from 32 to McArthur.
- Consider looking at the test section on US 50 west of McArthur even though this might be out of the region being considered; there is extra right of way there due to the testing which may be helpful.
    - o *Project manager Cynthia noted that the borders aren't tightly fixed so we can look at these suggestions.*
- Honestly, there are no areas to stay away from in my point of view.

John McAdam

- To inform the route or place to avoid, use TOAST data (it has information on impacts); the TMC also has anecdotal info – and access to WAZE data.

Jamie Hendershot

- EIMS – the project team could choose to look into the existing animal carcass/strike information we have on state routes as a resource. (Matt Bruning sent the link.)
- I will share capital program information for the team to use.

Additional comments

- There are four at-grade intersections we've worked on including Athens at Blackburn Road, US 50/CO/9 intersection, township 38/united lane to look into.
- 278 and 356 are each prone to frequent flooding so that's a consideration for the project team.
- US 50 is pretty consistent but there are a lot of closures.

- Operationally, do not test around Athens/Alexander High School off of US 50 and New Albany. There is a lot of congestion at the turning movements.
- South of Athens, there is limited access on 33 south to north of Pomeroy. It was built to four-lane standards, but currently is at two lanes.
- Be aware of the ROADMAP program, which is a Dept. of Energy Grant. It will look at electric public transit vehicles and also use a Tesla to test some (level 2) automation in the Athens area.

What are the considerations, opportunities and challenges around data collection from your perspective?

John Puente

- I'm not sure I understand what data you are collecting; I could use more information.
- Make sure there is no personally identifiable info relayed.
- I would like to see schema once data streams to see new data being managed to see if governance info.
    - *Cynthia Jones sent John Puente the Data Management Plan for his review.*

How do you see messaging about this project being best delivered to other road users and public stakeholders?

Erica Hawkins

- There are digital messaging boards on the entry to Athens on US 33 and US 50.
- There's also a Local Comm Rural Action Plan that hosts a forum every couple of months (it's a structured way to gather feedback from traffic and fleet operators).
- The communications mechanism that's most effective in this district is social media; it's a method we use frequently in this area and suggest that for this case as well.
- On stakeholders, get with them early and often, especially lawmakers, public officials, law enforcement. A regular e-news is one suggested method of communication.

Ashley Rittenhouse

- There could be value in doing public meetings and mailings as far in advance as possible.

Matt Bruning

- Be transparent and proactive. Let people know what's coming.
- People participating in the project may perceive we are viewing them as test rats, or, on the other hand, as leading edge depending on how they are introduced to the project.
- Matt is happy to help review talking points and provide input based on his expertise.
- The team should consider snail mail or social media as communication channels.
- Use digital messaging boards.
- There are also cameras at the 33/50 split on the north side near E. State St.

- Consider an on-site demonstration at the local high school – Vinton County has a K-12 campus west of McArthur. Jeff Kupko could come in and speak to the technology while it's in testing mode and help locals "touch and feel" the actuality.
- The Ohio University Airport is located on US 50 – could be a good idea to do a fly-in with elected and other officials for a demonstration; could have dignitaries ride in and do a site visit to allay fears (Director and the Governor could participate).
- Be conscious of concerns around the term "testing" – use the terminology "cutting edge" and get ahead of it; that said, say only what's needed. Honestly, many other road users may not know the test is going on if there are operators in the seat.
- Folks in southeastern Ohio and rural areas often feel "We want progress, not change".
  - Communications is different in urban versus rural vs a statewide audience delivery; think about wording, tone and voice for this audience as slightly different. Be sure to set expectations appropriately. Sell the sizzle, but don't make promises that are unreal; if it's not valuable, don't say it.

Darla Miller

- Be sure to keep the county engineers in Vinton and Athens engaged. Also, have township and village administration participate.

While the focus of this project is collecting data - not actually providing passenger service, what are the mobility and paratransit issues you see over the long term?

Chuck Dyer

- Concerned that clients will be nervous; it will depend on customers to ensure safety.
- HAPCAP has a large program – maybe fleets at OU campus? They would be a good partner

Cynthia Jones

- *We will need to find a vehicle to test automated wheelchair lift technology.*
  - *Chuck replied that he can help with this, although he noted that there is a lot of liability with who is owning the risk/insurance of lifting/helping the disabled individual.*
  - *Noted how the long-game focuses on adding to the independence of those with mobility impairments (allows them to self-regulate which substantively improves their health and wellbeing).*

Do you have any thoughts on safety implications?

Mike McNeil

- I'm not hearing any red flags from a safety perspective; this seems interesting and exciting.
- TMC oversight will help keep people aware.

What other things would you like us to consider or what have we missed?

Mike McNeil

- What about farm equipment on the roads? Also, what are the implications of the FCC changes? How will that affect V2V and infrastructure?
    - *Nick Hegemier: This won't be a huge issue – the vehicles will be using onboard cell technology to communicate, which the FCC decision doesn't affect. We will look at how poles with power interact with the equipment; there are some really close to the right of way.*

What other issues do you foresee?

Erica Hawkins

- I suggest preparing a crisis communications plan ahead of time.

What questions do you have for us?

Chuck Dyer

- How will automated vehicles find driveways?
    - *Jeff Kupko answered that the vehicle will be on an extensively pre-mapped fixed-route so it won't be needing to "find" things for the first time.*

Jamie Hendershot

- This is a very exciting and tremendous opportunity to test and inform the rest of the US.
- How testing will play out?
    - *Cynthia: Phase 1 – closed testing at TRC, 2 – testing on US 33, 3 – testing on US 50, 4 – on more challenging routes, 5 – testing on a 3-digit route.*

Question

- Are we testing on gravel roads?
    - *Gravel roads will probably not be part of the test, but that doesn't mean we are just looking at state highways. County roadways are under consideration as well.*

Question

- Could we mock-up a work zone if there isn't one already planned for the demonstration route?
    - *There is a high likelihood that a work zone will already be planned in the project area, but we will keep this option in mind if needed.*

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Group – State Safety Officials

May 13, 2021 | 9:00-10:30 AM | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- Chris Kinn, ODPS
- Michelle May, ODOT Office of Safety
- Derek Troyer, ODOT Office of Safety

- *Randy Butler, CDM Smith*
- *Nick Hoffman, MurphyEpson*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Mindy Justis, MurphyEpson*
- *Marie Keister, MurphyEpson (Moderator)*
- *Jeff Kupko, Michael Baker International*
- *Ben Ritchey, CDM Smith*
- *Roger Schiller, CDM Smith*
- *Jay Wilhelm, Ohio University*

FOCUS GROUP SUMMARY

Marie Keister moderated the state safety officials focus group which included a presentation and question and answer session. The brief overview presentation included specifics about Ohio's Automated Driving Systems (ADS) project including what it is and what will be demonstrated. Following the presentation Marie facilitated a series of questions to the three meeting participants. A summary of comments, questions and discussion is highlighted below. Once the user needs were collected the focus group was adjourned.

USER NEEDS

The following is a summary of user needs collected through comments, responses to questions and focus group discussion.

What reactions do you have to this demonstration? What questions do you have? What are your preliminary thoughts?

Derek Troyer

- When installing poles locate them on the inside of curve, which is less destructive (most vehicles that run off the road, go to the outside lanes.)
- Depending on which test routes are chosen, team may want to supplement previous TIMS data regarding striping, lane widths, etc. You'll want the exact status of the roadway at the time of the testing.
- ***Roger Schiller:***
    - *Team will be collecting Lidar data/mapping.*
- ***Jeff Kupko:***
    - *Team will be run and map the routes and pull in all the needed data; live mapping will be compared to stored mapping to identify differences. Pre-processed data may not be helpful unless all aspects are included.*
- Also review SHRP2 and RID data sets and what data those national studies collected.
- Project team asked Derek Troyer to review the ADS Data Management Plan and offer insights.
- Coordinate with ODOT Office of Roadway Engineering when using digital message signs. It's a process.

What should we be thinking about on the law enforcement side of ADS?

Chris Kinn

- The law enforcement approach to ADS is going to be similar to the public approach. Officers are from the same rural Southeast Ohio area and will have the same questions. Consider a marketing campaign.
- There is fear of the unknown; American population in general may not welcome driver-less vehicles but there are automated features that they desire (i.e. safety systems); need general awareness for public.
- Team should work with State Highway Patrol on potential traffic crash investigation/mitigation strategy and train officers.
- SHP has lots of crash data available.
- Will ADS vehicles be identified or marked, or operate covertly? My opinion is it is better to mark ADS vehicles, which may build consumer/public confidence and awareness.
- ***Roger Schiller:***
    - *If passenger vehicles are platooning do they need a different marking to alert other drivers they are in platoon mode?*
- Platooned vehicles should have some marking/identification when they are platooning, as they would be traveling closer distances than what is standard and

they would alert law enforcement (Ohio's following too close law). Maybe use a special light system on platooning vehicles to notify the public/other drivers.

- May want to test how other drivers react to platooning vehicles.

NOTE: Marie Keister asked participants about local safety and emergency contacts, and Chris and Michelle offered assistance.

Do your previous comments on the ADS passenger vehicle automation also apply to truck automation?

Derek Troyer

- The ADS demonstration is approaching the shale (oil) region and this industry employs multiple water trucks for its operation. Consider partnering with this industry with truck platooning.

Tell us more about your efforts to address safety and law enforcement related ADS concerns.

- As part of the Six State Trooper Projects (Ohio and neighboring states), SHP is developing and outlining a curriculum for all law enforcement officers, focusing on safety with electric vehicles and automation.
- Future automation levels 3, 4 and 5 will be a mind-shift on safety and law-enforcement (we'll need to shift to defect investigations, compared to at-fault driver investigations).
- When moving into levels 3 and higher, need to focus on safety driver response time (currently pilots have a 10-second response time; automobiles and trucks need a quicker response time to react to safety issues
- Demonstration should study safety drivers through monitoring eyes, pressure on steering wheel etc.

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Demonstration
Testing Automated Trucks and Passenger Vehicles in Rural Ohio
Focus Group – SE Ohio Local Partners 2

July 21, 2021 | 1:30 – 2:30 PM | Zoom Meeting

MEETING SUMMARY

ATTENDANCE

- Craig Borkowski, Terra Sound Technology
- Dave Holstein, ODOT
- Jeff McCall, Athens Police Department
- David Molihan, ODOT Vinton County Transportation Administrator
- Jeff Risner, Athens City Council, Ward 2
- Jesse Roush, Southeast Ohio Port Authority
- Robert Rymer, Athens Fire Department

- *Randy Butler, CDM Smith*
- *Tsigigenet Dessalgn, TRC*
- *Sarah El-Dabaja, ODOT D10*
- *Joshua Every, TRC*
- *Nick Hegemier, DriveOhio*
- *Nick Hoffman, MurphyEpson*
- *Greg Jankford, TRC*
- *Sam Khoury, Ohio University*
- *Cynthia Jones, DriveOhio (Project Manager)*
- *Marie Keister, MurphyEpson (Moderator)*
- *Jeff Kupko, Michael Baker International*
- *Roger Schiller, CDM Smith*
- *Tanner Thiessen, TRC*
- *Ken Troup, CDM Smith*
- *Andrew Wallace, DriveOhio*
- *Liz Webb, MurphyEpson*
- *Jay Wilhelm, Ohio University*

FOCUS GROUP SUMMARY

Marie Keister initiated the focus group meeting and Cynthia Jones welcomed and thanked everyone for participating. Following introductions, Marie provided a brief overview of both DriveOhio and Ohio's Automated Driving Systems (ADS) project. Marie then went into detail explaining the rural demonstration parameters, vehicle automation levels, goals and funding partners.

Following the presentation Marie asked participants a series of questions. Cynthia Jones, Nick Hegemier, Randy Butler, Jay Wilhelm and Greg Jankford and other team members provided responses to technical questions. A summary of the discussion is highlighted below. Once the user/stakeholder needs were collected the focus group was adjourned.

USER/STAKEHOLDER NEEDS & DEMONSTRATION DISCUSSION

Passenger Vehicle Discussion

Several maps showing potential ADS demonstration loop routes near Athens, Ohio were shown to focus group attendees. They were asked what concerns they may have about the routes.

Jeffrey Risner

- Most of the route isn't in Athens jurisdiction – need to talk to commissioners and township trustees (townships: Athens and Alexander Townships)

Bob Rymer

- Route does go into the Athens Fire Dept jurisdiction and some other volunteer jurisdictions; Athens FD has a mutual aid response in those jurisdictions. This loop gives you what you're looking for in road variety. No issues with school jurisdictions or EMS. Stakeholders involved to reach out to: OUPD, Athens PD, Sheriff's Dept., Richland Volunteer FD, Athens FD. There are railroad tracks in that area too (Norfolk Southern contracted out to Kanawha in Charleston, WV).
  - Richland Volunteer FD: Chief Dale Sinclair (740) 818-6343
  - Bob offered to try and help connect to Kanawha

Bob Rymer

- Asked about what support there will be for crashes.
  - ***TRC:*** *There will be professional drivers on board and research teams on site.*
- One concern is proximity to EMS station.
- Elliot road is not the best road.
- There is some construction planned in the next few years.

Jeffrey Risner

- 682 and 56 roundabout construction may start in 2022 or 2023; there might be some upgrades around Shaffer towards Larry's Dog House to intersect with W. State Street. Dealing with construction at that time.
- Morrison-Gordon Elementary and Beacon School in Athens School District in area.
- Contact Jessica Adine (jadine@ci.athens.oh.us) for all road updates.

Greg Jankford

- With regards to construction, is there a site map of expected construction available?
- *Jeffrey Risner*: *Contact Jessica Adine.*

Craig Borkowski

- Concerns with camera system in terms of seasonality. Snowfall could affect spatial location of cameras—are there any safety considerations?

- o ***Randy Butler****: Yes, a complete safety plan will be created and will take into consideration all these concerns. Should be available around January 2022.*
- o ***Marie Keister****: There will be a crisis comms plan as well should anything occur.*

When looking at potential map routes from Athens to McArthur:

Jeffrey Risner

- There is only one traffic light in McArthur, maybe some caution lights. Are you planning on going off 677? That's the route with the most tree canopy you could get in Zaleski State Forest. There is also a dynamite factory on that road with trucks hauling explosives.
  - o ***Jay Wilhelm****: That is one option. Good to know about the dynamite.*

Focus group attendees were asked about any public outreach considerations but there were no comments on this.

Truck Discussion

Jeffrey Risner

- Are these full-size tractor trailers? Some weight considerations if trucks go into town.
  - o ***Randy Butler****: Yes, class 8 tractor and 53 ft trailers.*
  - o ***Cynthia Jones****: We want the host fleet manager to use their local routes.*
- Kerr's Distribution is a local distributor. I don't know how that would fit in, but these trucks stay parked in loading zones for a minute while doing deliveries. Also, there is a Pillsbury distributor.
  - o ***Cynthia****: There is an RFP going out in the next few months to recruit companies in the area who are open to this technology. This will be shared widely.*
  - o ***Marie****: Send us the contact info for beer distributor; we can Google the Pillsbury facility.*
- Other distributers include Southeast-beverage and Rocky Boots (Distribution center on 33 south of Logan. HQ in Nelsonville)

Dave Holstein

- What is your evaluation trying to get to? Striping, etc.
  - o ***Nick Hegemier:*** *As far as mapping, it's going to be a big task on local and state DOTs to keep up with updates. Has seen instances with implications of mapping when road stripes change.*
- Will striping and wax sealing in the area be an issue?
  - o ***Nick Hegemier:*** *Yes, it will be interesting to see how all these aspects operate in the test.*
  - o ***Greg Jankord:*** *One of the big insights that we're trying to draw from studies like this is as we continue to diversify the operating environment, what infrastructure challenges exist and what we need to add to the vehicle? Until you take the vehicles out in these new operating environments, you aren't going to learn. So, one of the things that TRC is doing is we're trying to determine what infrastructure needs to be considered to be ADS ready. It will be an output we are delivering on this project.*

End User/Stakeholder Needs Summary Presentation

DriveOhio

The Future of Smart Mobility

DriveOhio

The Future of Smart Mobility

Automated Driving Systems (ADS) Project

End User/Stakeholder Needs Summary

June 2021

Ohio Department of Transportation

End User/Stakeholder Focus Groups conducted by MurphyEpson

Presentation Overview

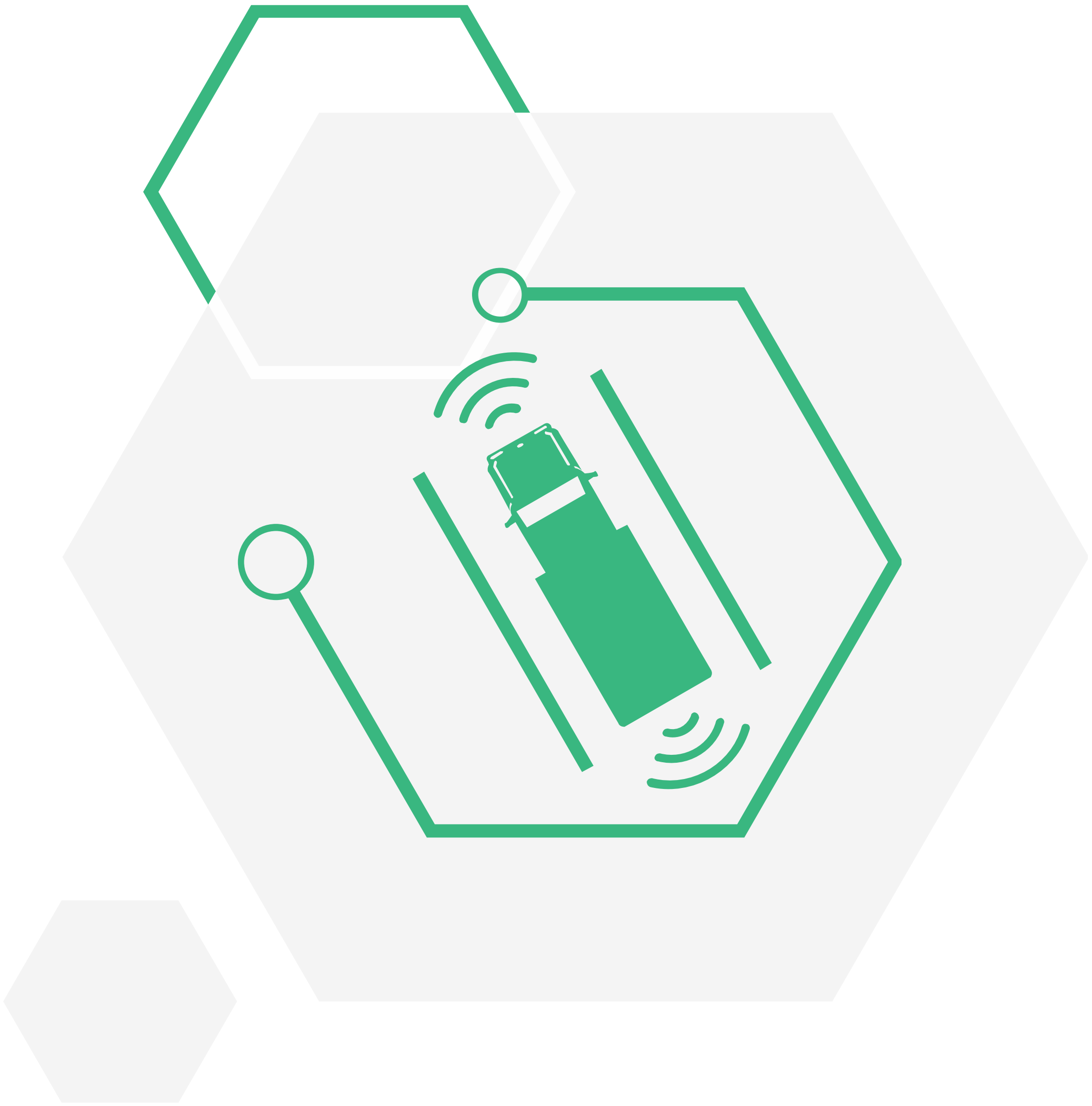
- Focus group/input overview
- Automated truck input
- Automated passenger vehicle input
- Input on both trucks/passenger vehicle automation
- Next steps

Pauses for comments and questions throughout

6 Focus Groups

35 attendees

- Local partners
- Logistics associations
- State safety officials
- USDOT, FMCSA, FHWA, FTA
- ODOT (2 groups)



Participants

- Buckeye Hills Regional Council
- DriveOhio
- Gallia County Engineer
- Ohio Department of Public Safety (ODPS)
- Ohio State Highway Patrol (OSHP)
- ODOT Central Office
- ODOT District 10
- Ohio University
- Ohio Trucking Association
- Columbus Region Logistics Council
- FMCSA
- FHWA
- FTA
- SIXMO City Service

Grouped Input into Six Categories

- Vehicle automation
- Vehicle/roadside infrastructure communication/routes
- Operational uses
- Safety and enforcement
- State and federal policy
- Community impacts/communication

Automated Truck Input

Truck Automation

- Lane keeping is fairly common now on trucks; test the value of additional automation when all added together (can be clunky)
- Concerned Level 2 is basically just adaptive cruise control on steroids
- See NHTSA report/standards on breaking distance, Level 2 functional safety study

Truck Automation, Cont.

- Seek to understand driver fatigue, boredom and complacency
  - See FAA research on pilot reaction time
  - See FMCSA/USDOT work on video-based sensors of driver brainwaves. This is being done in California/NM/Texas study; okay to duplicate that for more data since we don't know what we don't know
- Freightliner, Bendix about to manufacture Level 2 trucks
- Platooning not yet in production

Truck/Roadside Infrastructure Communication & Routes

- Concerned about wearing surfaces of roadway and future uses of ADS (e.g. natural gas industry truck volumes)
- Want to learn where ODOT infrastructure can be improved; this helps traffic managers

Route ideas

- US 35 has higher truck traffic than US 33, truck stops are at capacity and trucks park overnight along US 35
- US 33 goes from 4-lanes to 2-lanes south of Athens and has hilly, curvy terrain

Truck Operational Uses/Platooning

- Determine whether freight density supports platooning – is there a business case/ROI?
- Ask fleet operators:
  - What systems they have to measure fuel and productivity savings
  - How do we integrate their data collection (outlined above) with ours
  - Safety benefits for 2nd driver
- If can't find participating carrier, simulate cargo weight with bricks of concrete

Platooning candidates

- Water trucks in shale/natural industry in eastern Ohio
- Time critical and high quantity deliveries (e.g., fuel haulers, animal food)
- "Pool distributors" – e.g. All Pro Freight Systems

Truck Operational Uses/Workforce

- Drivers fear losing jobs to automation
- Drivers today also fear operating big trucks/large machinery = increased automation may actually make job more attractive
- Ideas to get workforce excited
  - Trade show engagement
  - Tech/fleet career days and talent fairs
  - Ride alongs during closed track testing

Truck Operational Uses/Other

- Meet with participating carrier bi-weekly to work through insurance, liability, training and operations issues
  - FMCSA will share training materials from California ADS demonstration once finalized (about one year ahead; Ohio can benefit from lessons learned)
- What is cost/benefit analysis in addition to the safety/ research benefits?
- One goal of demonstration could be to expose the industry to the tech realities
- Having the technology and a market need are two different things

Truck Safety and Enforcement

- Involve state patrol early and often
- Patrol officers may also be wary of the new technology
- In CA, state patrol asked that trucks have an indicator light when in platooning mode
- Confirm laws on following distance in Ohio; get waiver if needed

Truck – State and Federal Policy

- What license plates will be used?
- What type of permitting will be required? Get the BMV/DPS involved early
- FMCSA/USDOT wants all 8 ADS grant winners to learn from each other
  - Would like to see grant details summarized in one chart at some point

Questions & Discussion

Automated Passenger Vehicle Input

Passenger Vehicle Automation

- FHWA concerns about Level 3 automation:
  - Aviation studies show it takes 10 seconds for a human to react and take over an automated function
  - Reduce driving time durations to lessen driver fatigue or boredom
  - Review research and see SAE recommendations

Passenger Vehicle Automation, Cont.

- Automated vehicles are not distracting to other travelers when there are “drivers” in the automated vehicle but once the “person” is removed it becomes alarming
- Having 3 or 4 platooning passenger vehicles could be disruptive to the public; probably not a problem on straighter, limited access routes but avoid this in high crash locations
- Don’t need ADA-compliant vehicle since no passengers will be onboard
  - Youngstown project will test automated functions for ADA services
  - Contra Costa County hospital system providing Level 3 and 4 ADA shuttle service traveling up to 50 MPH (April 2021 kick off)

Passenger Vehicle/Roadside Infrastructure Communication

- Consider interaction with slow moving farm vehicles
- Seek mapping parameters from AutonomouStuff
- FMCSA will want to review ADS test plans; should complement what others are doing nationally. Collaboration encouraged.
- How does the vehicle communicate its intent to other road users?
- How does vehicle interact with vulnerable road users?

Passenger Vehicle/Roadside Infrastructure Communication – Route Ideas

- US 50 east to US 33 (cameras here)
- See pavement test section on US 50, west of McArthur
- Test grades from State Street (Athens) to US 50 and US 33
- Baker Road is narrow, curvy and has no pavement markings
- Recent safety investments at four at-grade intersections: Athens at Blackburn Rd., US 50/CO 9, Township Rd. 38/United Lane
- SR 278 and 356 prone to frequent flooding

Passenger Vehicle/Roadside Infrastructure Communication – Route Ideas

- Avoid Athens/Alexander High School off of US 50 and New Albany
- Be aware of the ROADMAP Dept of Energy grant – doing Tesla and connected, autonomous, electric vehicle testing for public transit (HAP-CAP)
- Use TOAST data to inform route selection or areas to avoid
- TMC can provide anecdotal data and input from WAZE

Passenger Vehicle Safety and Enforcement (will follow up)

- Consider having a local law enforcement plan
- Ask what resources and reassurances safety officials need to trust ADS operations and testing on public roads
- Ask EMS and other safety providers their concerns on how ADS vehicles will function with emergency vehicles
- Manufacturers also interested in understanding concerns from law enforcement, EMS, local weigh stations

Community Impacts/Education (will follow up)

- Ask transit agencies how customers might feel about using ADS vehicles – see ROADMAP
- Ask for public input on perceptions of ADS vehicles interacting with pedestrians and bicyclists
- There are mobility barriers to rural populations including older adults, those with disabilities or substance abuse issues – this could reduce overhead of service delivery and increase on demand transportation services

Questions & Discussion

Input for Both Vehicle-Types

Vehicle Automation

- Monitor eyes, pressure on steering wheel, etc.
- Both passenger and truck vehicle data will be useful for logistics organizations

Vehicle/Roadside Infrastructure Communication

- Consider wildlife interaction
  - Buckeye Hills removes animal crash strikes in data since there are no countermeasures they can provide
- Consider broadband, connectivity, topography clocking signals, lane markings
- How critical is it to pick up the road centerline to operate?
- Roadway mapping is not very robust in rural U.S. – roadway length, width, speed, etc.
- 40% of Gallia County has zero cell service/signals

Vehicle/Roadside Infrastructure, Cont.

- Review SHRP2 and RID data sets and what data those national studies collected
- Have data management plan reviewed by Derek Troyer (Office of Safety), John Puente (DGO) and Charles Ash (DoIT)
- State Highway Safety Plan has extensive crash data
- For dangerous roadway locations, see state routes near traffic signals; review each county's crash statistics
- Many state highways in SE Ohio have guardrails but township/local roads do not

Vehicle/Roadside Infrastructure, Cont.

- Consider testing on dirt/stone roads, which are common in rural areas
- Advisory speeds along curved roads are not always posted
- Flooding events could be an issue
- Smaller roads don’t always have edge lines
- When installing poles/equipment locate them on the inside of roadway curves, which is less destructive (when vehicles run off the road they tend to go to the outside lanes)

Safety and Enforcement

- Work with State Patrol to discuss traffic crash investigation/mitigation strategies and officer training
- State Highway Safety Plan has extensive crash data and is developing a curriculum for law enforcement on EV/automated vehicle safety (may be available in 6–12 months)
- Levels 3–5 automation will require safety/law enforcement mind shift
    - From at-fault driver investigations to vehicle-defect investigations

Community Impacts/Communication

- ODOT Comms recommends adding signage/lights on ADS vehicles and at test areas to boost public awareness and confidence in the technology
  - Coordinate with ODOT Office of Roadway Engineering to use digital message signs in testing areas (it's a process)
  - May want to test how the public reacts to this
- Allow many opportunities for the public to learn, see and touch the technology
  - Consider creating or participating in events to showcase the testing vehicles (OU fly in? Event at local school system?)

Community Impacts/Education

- Engage TMC, public officials, county engineers, transportation/ planning managers – arm them with materials so they can share with their constituencies
- Inform/engage the public through website, media relations, events, traffic reporters – and social media, which is very effective in SE Ohio
- Do a blitz 30 to 60 days in advance of the deployment in addition to ample pre-engagement with local stakeholders to minimize/manage public concerns
- Prepare a crisis communications plan

Community Impacts/Education, Cont.

- Cultivate AV champions
- Help the community understand these mobility opportunities are down the road yet but not 50 years away
- There is a cool factor here; communicate that
- There is fear of the unknown:
  - "We want progress but we don't want change"
  - "Give us ownership of our own destinies – we don't like big government taking over"

Questions & Discussion

Next Steps

Outcomes/Next Steps

- ✓ Reconfirm Communication & Engagement Plan incorporates stakeholder input and begin implementation
- Submit Summary Report
  - Includes each meeting summary in appendix
- Engineers will further refine end-user needs in ConOps
- Schedule additional engagement sessions (engage now/early; update prior to launch; keep informed throughout)
  - Local technical officials – county garages, city/county engineers, sheriff/police departments, EMS
  - Logistics organizations (Dayton and Columbus, port authorities, etc.)
  - Local community officials – elected officials, community organizations

Thank You

Appendix C3
Automated Driving Systems (ADS) Demonstration-Rural ADS Stakeholder Workshop

DriveOhio
Advancing Smart Mobility

Automated Driving Systems (ADS) Demonstration
Rural ADS Stakeholder Workshop

January 18, 2023 | 2:00 – 3:30 PM | Nelson Commons, Ohio University, Athens, Ohio

MEETING SUMMARY

MEETING PURPOSE

Inform stakeholders about the Automated Driving Systems (ADS) demonstration, its purpose of data gathering, to excite stakeholders and seek their input on possible uses of audio-visual technology in the future.

TARGET AUDIENCES

- Local elected officials
- Transportation professionals
- Local healthcare
- Transit and social service agency leaders

ATTENDANCE

- [redacted], City of Athens
- [redacted], CDM Smith
- [redacted], DriveOhio
- [redacted], DriveOhio
- [redacted], DriveOhio
- [redacted], Greater Ohio Policy Center
- [redacted], HAPCAP (Athens County)
- [redacted], HAPCAP (Hocking County)
- [redacted], JobsOhio
- [redacted], Meigs County JFS
- [redacted], Morgan County Mobility
- [redacted], MurphyEpson
- [redacted], MurphyEpson
- [redacted], ODOT District 10
- [redacted], ODOT District 10
- [redacted], Ohio University
- [redacted], Ohio University
- [redacted], Ohio University
- [redacted], Ohio University (student)
- [redacted], TRC
- [redacted], TRC
- [redacted], TRC
- [redacted], TRC
- [redacted], TRC
- [redacted]

DriveOhio
Advancing Smart Mobility

MEETING OVERVIEW

DriveOhio and its partners held a stakeholder workshop for the Automated Driving Systems (ADS) Demonstration on Tuesday, January 17, 2023, from 2:00-3:30 PM. The workshop was hosted by Ohio University and the Russ College of Engineering and Technology at Nelson Commons, on the campus of Ohio University, in Athens, Ohio. The meeting format included a presentation, followed by table discussions and table report out. Light refreshments and parking were provided.

Workshop participants were welcomed by [redacted], Service Safety Director with the City of Athens, and [redacted], Interim Dean of the Russ College of Engineering and Technology. [redacted] led participant introductions and presented the meeting format. [redacted] then provided an overview of the project goals, process and schedule. [redacted] discussed the ADS technology and future opportunities, while [redacted] provided an overview of the test vehicles and routes, challenges facing the technology and the preliminary deployment plan.

[redacted] provided instructions to workshop participants, who had roughly 30 minutes to discuss and document their ideas, thoughts on transportation challenges and how to overcome these challenges. The participants were also encouraged to note any local organizations that might collaborate with the ADS demonstration. This feedback was collected through worksheets and key table takeaways. Following the table discussion, [redacted] facilitated a report out where participants provided their table's key takeaways during the discussion. [redacted] then shared next steps before the meeting was adjourned.

WORKSHEET SUMMARY

Question 1. Participants were asked if they have clients, customers, friends, or family that have transportation challenges. Their responses are shown below.

- 17 Yes
- 1 I don't know
- 0 No

Question 2. The participants were then asked if those people do have challenges, to list what those challenges are. Their responses are shown below.

- 15 listed they don't drive due to age or disability
- 13 listed they don't have access to a vehicle
- 13 listed they don't walk because it's too far to get to their destinations
- 13 listed they don't ride a bike because it's too far to get to their destinations
- 13 listed they don't ride public transit because it doesn't come frequently enough
- 13 listed they don't ride public transit because it doesn't take them where they need to go
- 13 listed they don't ride public transit because it takes too long to get them where they need to go

- 12 listed they don't ride public transit because it doesn't operate during the hours when they need it
- 11 listed they don't ride a bike because it doesn't feel safe *(e.g., few or no bike trails or bike lanes on streets)*
- 10 listed they don't drive because of personal preference
- 10 listed they don't have anyone to drive them to their destinations
- 9 listed they don't walk because it doesn't feel safe *(e.g., few or no sidewalks, no lights, etc.)*
- 7 said there were other reasons (*not listed)*

STAKEHOLDER TABLE DISCUSSION

Question 3. Participants were asked about ways that an automated vehicle might overcome challenges in rural communities. Their responses are below.

- Solve staffing issues for public transit
- Assist individuals who have mobility impairment
- Increase productivity for drivers who make long commutes
- Improve overall safety for drivers and pedestrians
- Transportation option for foreign individuals who are unable to drive
- Overcome distance issues for individuals who walk & bike
- Future thinking for rural areas by development of the road systems, including adding sensors
- Adding additional hours when typical public transit isn't available, including holidays and weekends
- Reduce impaired driving related instances
- Reduce reliability issues of vehicles
- Delivery in remote places including food, medical items and other goods/services
- Cost- effective way to bring transit to play where it currently does not exist
- Automated taxis
- After school transportation for kids
- Assist new employees with a cheaper option to get to and from work
- Safe alternative for those with disabilities, who do not feel safe driving
- Safe alternative for those who do not feel safe driving in inclement weather
- Educational piece in the technology. What does it look like and how can we help?

Question 4. Participants were also asked what local organizations would be willing to participate in a pilot demonstration. Their responses are shown below.

- Athens Public Transit
- City of Athens
- 4-H clubs
- Local hospital
- Assisted living organizations
- Grocery Stores
- HAPCAP
- SCOJFS (medical clients)
- Board of DD
- L-H school district
- Ohio University
- Athens County tourism
- Meigs County Public Transit

Appendix C4
Automated Vehicle Educational Presentation-Pre and Post Survey

Automated Vehicle Educational Presentation: Pre and Post Survey

Overview

A total of 58 adults (aged 40-90+ years) from six locations across Ohio participated in a survey study that aimed to assess perceptions of automated vehicles (AVs). The study consisted of a demographic survey, a survey that assessed perceptions of AVs (Survey 1), an educational presentation on AVs, and finally the same survey that assessed perceptions of AVs (Survey 2). A statistical analysis was conducted to determine if perceptions of AVs, based on responses from Survey 1 and Survey 2, changed after the educational presentation. It was found that in general, providing older adults with enough information concerning automated vehicles would alleviate their concerns about the safety and operation of these vehicles. Increasing the familiarity of these populations with the advanced technology will allow them to better adopt and integrate the technology in their lives in the future. Although the sample size was different, some attitude difference towards automated vehicle technology was observed between rural and suburban population, due mainly to the familiarity of the suburban group with automated vehicle technology from previous interactions.

Methods

Senior centers across Ohio were contacted as potential locations to conduct this survey study, and six locations responded. Each location advertised the study to adults in its respective area and were explained that participation was voluntary. At each location, the study took place in a large room that would comfortably accommodate the number of participants and an audio-video system was provided to provide visual aids.

Upon providing consent, participants were provided a demographic survey (Appendix A) and was followed with Survey 1, which assessed their perceptions of AVs. The survey (Appendix B) listed 20 statements and participants were prompted to rate each statement on a scale of 1 (strongly disagree) to 7 (strongly agree). Statements were worded so that higher levels of agreement indicated acceptance of automated vehicles. Once completed, the researcher(s) provided an educational presentation on AVs, including an overview of the technology used and safety features. The participants then completed Survey 2, which consisted of the same questions as Survey 1. The demographic survey and the pre- and post- presentation responses (Survey 1 and 2) were stapled together for each respondent so changes in attitudes could be tracked without identifying the respondent. An AV was made available to view at the conclusion of the study.

Participant Makeup

Six groups of adults participated in this survey that was conducted in locations across Ohio: Marion (2), Sandusky (2), Woodsfield (1), and Grove City (1). Grove City is a suburb of Columbus and Woodsfield is a village, while the other sites were small cities in rural areas. (Table 1 showcases population values and size classifications.) A pilot study was conducted in Athens as a means to assess and refine the original survey before administering it to the final six locations. An automated vehicle was taken to each location, except Marion, and participants were offered the opportunity to explore the vehicle after completing the survey.

Table 1. Population and characteristics of cities holding focus groups.

Location	Population	Population Date	Status	Region of Ohio
Marion	35,999	2020	city	central
Sandusky	24,758	2021	city	north central
Woodsfield	2,120	2020	village	southeast
Grove City	41,252	2020	suburban city	central
Athens (pilot)	24,311	2021	city	southeast

Demographic Results

Participants completed a demographic survey that asked about characteristics such as age, occupation, and driving habits (Appendix A.) The responses are summarized in Table 2 and the following graphs. The majority of the participants were White (98%) and Female (72%). One respondent (2%) was Black and 16 respondents (28%) self-identified as Male. The majority of the participants reported being between the ages of 60 and 89 (86%). With respect to vehicle use and access, 91% of respondents were licensed drivers, 86% owned a motor vehicle, 95% relied on a vehicle to access services in their community, and 78% lived at least ten minutes away from the town center. The majority of the participants (81%) indicated that they were aware of the concept of AVs.

As seen in Figure 2, 55% of respondents reported having at least some level of college education, and 36% indicated having a high school diploma as their highest level of education. Typical with the age groups represented, 71% indicated they were retired, followed by 19% reporting that they volunteer, as seen in Figure 3. Most of the participants (84%) indicated that they drove at least some time (Figure 4). More participants (45%) indicated that they make 6 to 10 trips per week as compared to the other trip frequency options (Figure 5). Only 29% of participants stated they did not know how to access the internet on a smartphone or computer (Figure 6.)

Additional demographic questions related to perceived current and future health conditions (Table 3). The majority (76%) indicated that they don't have a medical condition that affected their driving, but a similar percentage (74%) anticipated having such a condition in the future. About a quarter (28%) serve as a driver for someone who cannot drive due to their health, while a larger percentage (45%) anticipated serving as such a driver in the future.

Table 2. Participant responses to demographic questions.

		Female	Male	Female	Male
DQ1	What is your gender identity?	42	16	72%	28%
		White	Black	White	Black
DQ3	Please indicate your race/ethnicity	57	1	98%	2%
		Yes	No	Yes	No
DQ6	Do you have a valid driver's license?	53	5	91%	9%
DQ7	Do you own a working motor vehicle, such as a car/truck/ or motorcycle?	50	8	86%	14%
DQ8	I reply upon a vehicle to access services (e.g. grocery story, bank, etc.) in my community.	55	3	95%	5%
DQ9	I would have to drive/ride at least 10 minutes to get to the town part of my community	45	13	78%	22%
DQ12	Do you have regular and reliable access to the internet at your residence?	40	18	69%	31%
DQ18	I am aware of the concept of an automated vehicle.	47	11	81%	19%

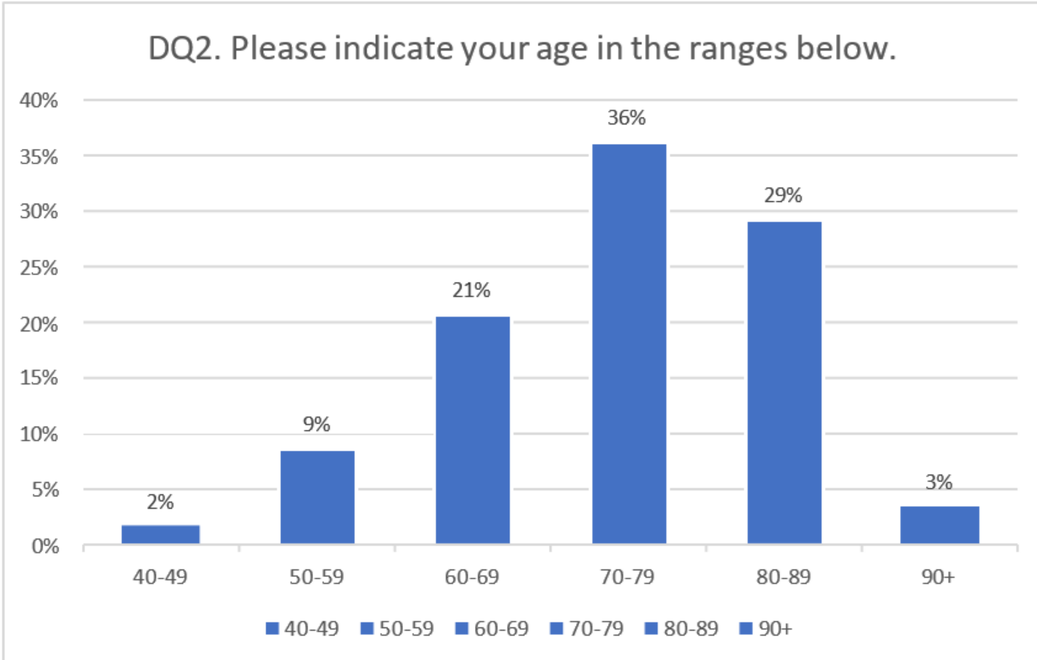


Figure 1. Age of focus group members.

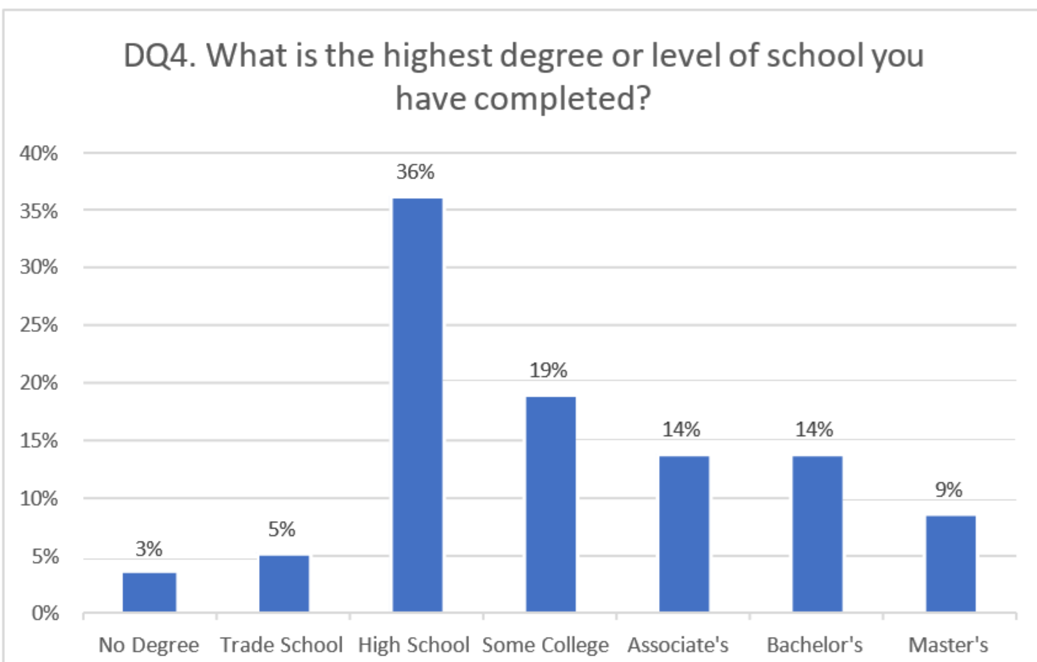


Figure 2. Education level of focus group members.

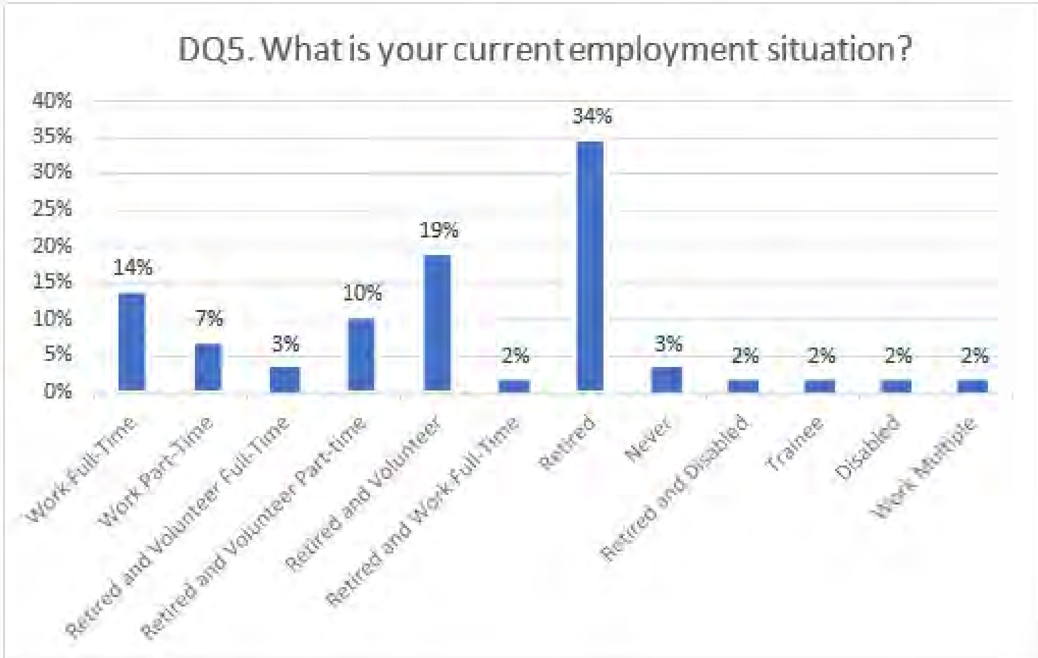


Figure 3. Employment status of focus group members.

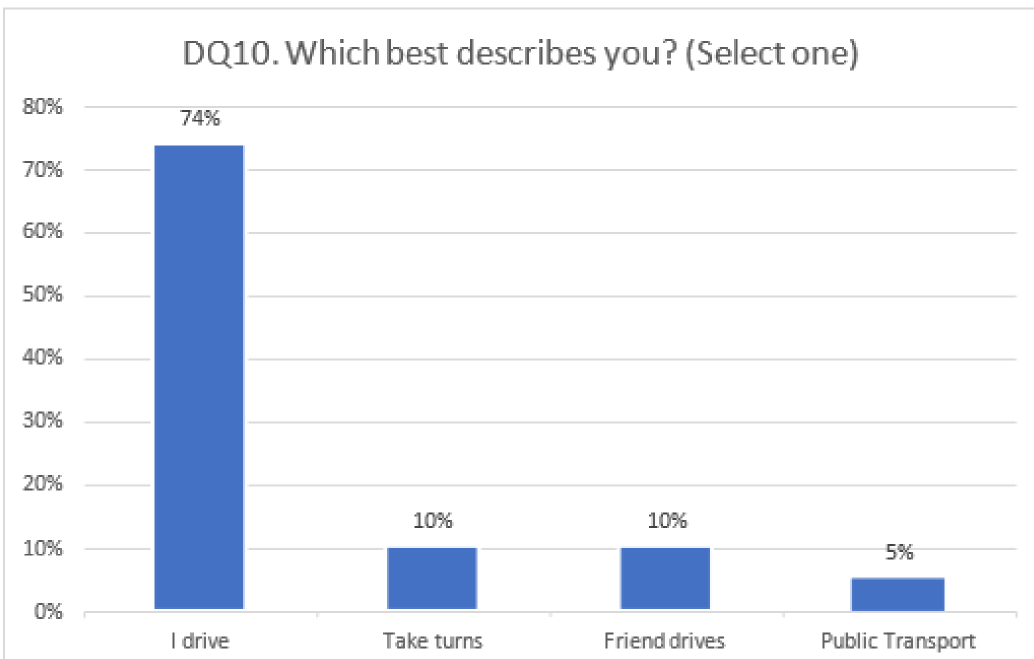


Figure 4. Driving status of focus group members.

Figure 5. Trip frequency of focus group members.

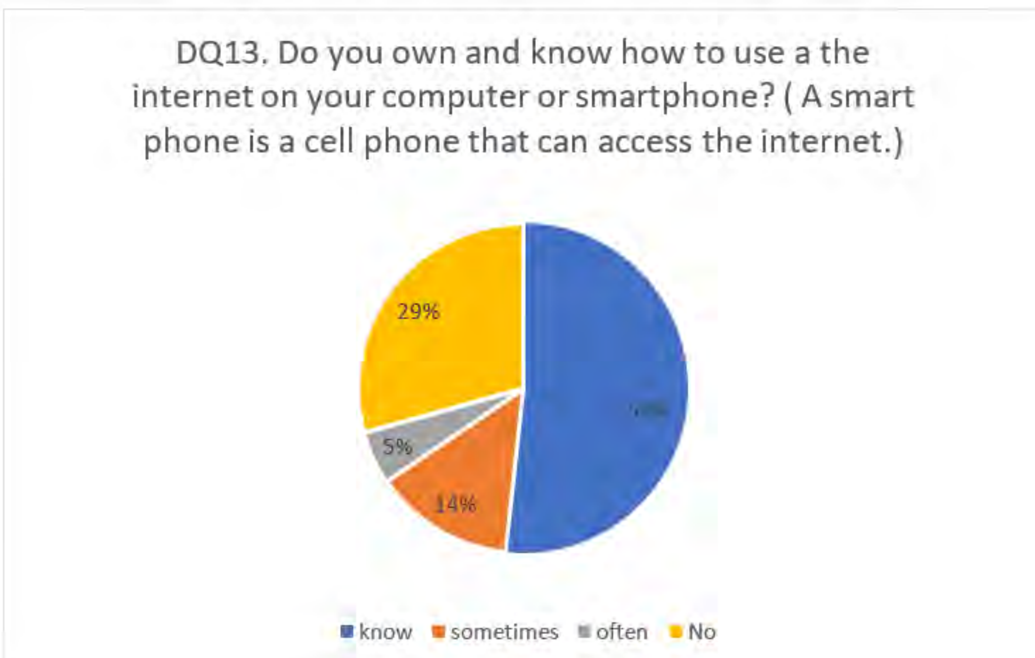


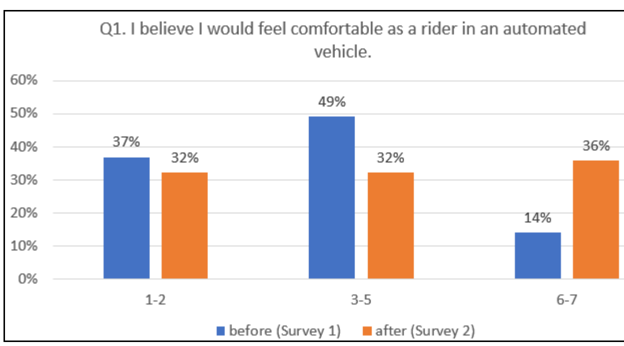
Figure 6. Internet usage and familiarity of focus group members.

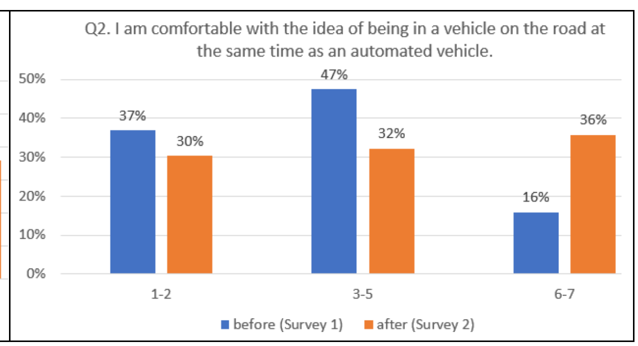
Table 3. Focus group responses to demographic questions 14 through 17 regarding driving. "N/A" means "not applicable – I do not drive".

		Yes	No	N/A	Prefer not to answer	Yes	No	N/A	Prefer not to answer
DQ14	If you drive, do you have a medical condition that influences your ability to drive safely at any time (day or night)?	11	44	2	1	19%	76%	3%	2%
DQ15	If you plan to continue driving in the future, do you think you may have a medical condition at some point that may influence your ability to drive safely at any time (day or night)?	43	11	2	2	74%	19%	3%	3%
DQ16	I am currently a regular driver for someone who cannot drive due to a health condition.	16	40	2	0	28%	69%	3%	0%
DQ17	I believe it is somewhat likely that at some point in the future, I may be a regular driver for someone who cannot drive due to their health condition.	26	23	3	0	45%	40%	5%	0%

Survey Results

The responses to each survey question are plotted in Figure 7 (Questions 1-10) and Figure 8 (Questions 11-20). Numeric responses were lumped into three categories: "Disagree" [1-2], "Neutral" [3-5], and "Agree" [6-7]. The following graphs plot the response counts from Survey 1 (blue bars) and Survey 2 (orange bars). There is a consistent pattern where the counts for the "Agree" category increase from pre-presentation to post-presentation. This suggests that the educational presentation influenced participants to have more favorable perceptions of AVs. Detailed response percentages for all questions from Survey 1 are tabulated in Appendix C and those for Survey 2 are in Appendix D. The average response on the 1-7 scale ranged from 3.46 to 5.07 for all the questions (neutral range). The averaging of each statement average on Survey 1 was 4.03 and 4.29 for Survey 2. There was a standard deviation of about 2 for each question, which suggests there were some changes in opinion between survey 1 and survey 2.





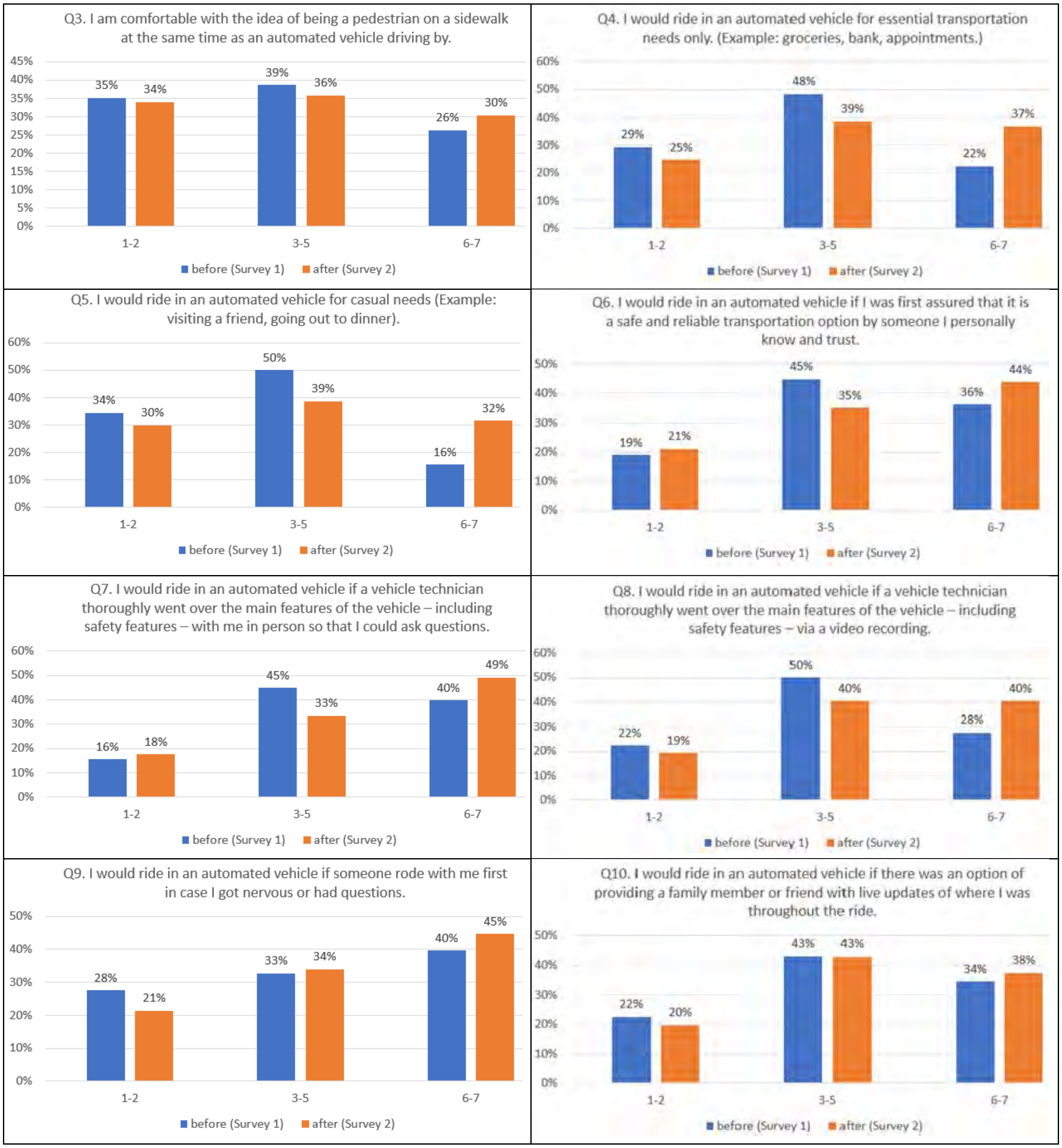


Figure 7. Responses to survey questions 1 through 10 before (blue/left bars) and after (orange/right bars) presentation. Responses to presented statements were rated on a scale of 1 (strongly disagree) to 7 (strongly agree), and clustered into disagree [1-2], neutral [3-5] and agree [6-7].

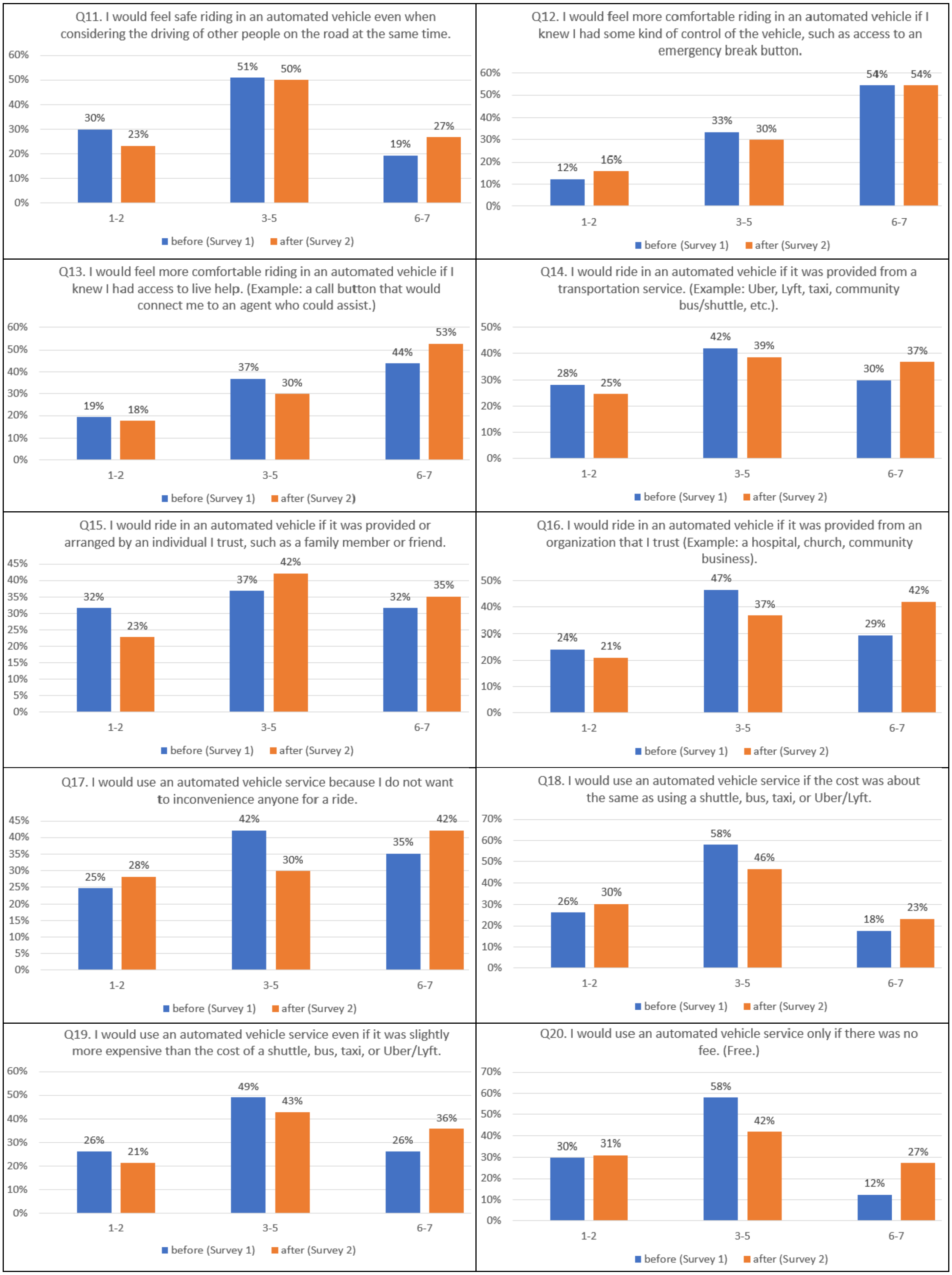


Figure 8. Responses to survey questions 11 through 20 before (blue/left bars) and after (orange/right bars) presentation. Responses to presented statements were rated on a scale of 1 (strongly disagree) to 7 (strongly agree), and clustered into disagree [1-2], neutral [3-5] and agree [6-7].

Because the before and after responses for each respondent were paired by stapling the questionnaires together, it is possible to track the changes in opinion for each respondent. Changes are on a scale of -6 (change from an initial rating of 7 before presentation to a rating of 1 after the presentation) to +6 (change from an initial rating of 1 before presentation to a rating of 7 after the presentation). The actual changes observed were typically far less extreme, given that most responses were in the neutral [3-5] range on both surveys. About half or more respondents (45.5% to 68.4%; average 57.8%) there was no change. However, changes of +1 (7.0% to 21.4%; average 14.6%) and +2 (1.8% to 18.2%; average 9.8%) outweighed those of -1 (1.8% to 15.8%; average 7.6%) and -2 (0.0% to 5.3%; average 1.8%), which comports with a generally greater level of agreement with the survey statements after the presentation, as observed previously.

The average change in response (after response – before response) for each survey question is plotted in Figure 9, along with error bars representing the standard deviation of the mean (standard deviation divided by the square root of the number of respondents (in this case, only people who responded to the question both before and after)). The first thing to note is that for every question, the net change in response was greater than zero, even if only slightly. If the error bars are shorter than the mean bars, that indicates there was a significant change in attitude after the presentation relative to before for that particular question. This appears to be the case for Questions 1 through 5, 7 through 11, 14 through 16, and 19 through 20. While Questions 6, 12, 13, 17, and 18 did show positive differences, they were not larger than the error bars and so judged not significant. The average change for each question is tabulated in Appendix E, and these range from +0.02 for Question 18 to +0.58 for Question 2, with the overall average being +0.31.

Figure 10 shows the average differences with respondents grouped into rural (blue bars) and suburban (orange bars) populations. As noted in Table 1, Grove City is a suburban city near Columbus, while the other sites were classified as rural, being smaller cities, or in the case of Woodsfield, a village. The focus group in Grove City included 9 people, and the remainder was 47 people (excluding one respondent who left the post-presentation survey entirely blank). The small size of the suburban response group makes those error bars relatively large. There are some clear differences in which questions had the largest changes between the two groups. For example, Question 3 had a net positive difference in the rural group, while there was no change for the suburban group. There was even a net negative change for the suburban group on Question 18, but the large error bars indicate this is not significant. The greatest positive change for rural people was for Questions 1 through 4 (not so much 2) and 20, while more positive change in the suburban group was seen for Questions 6 through 9, 16, and 19.

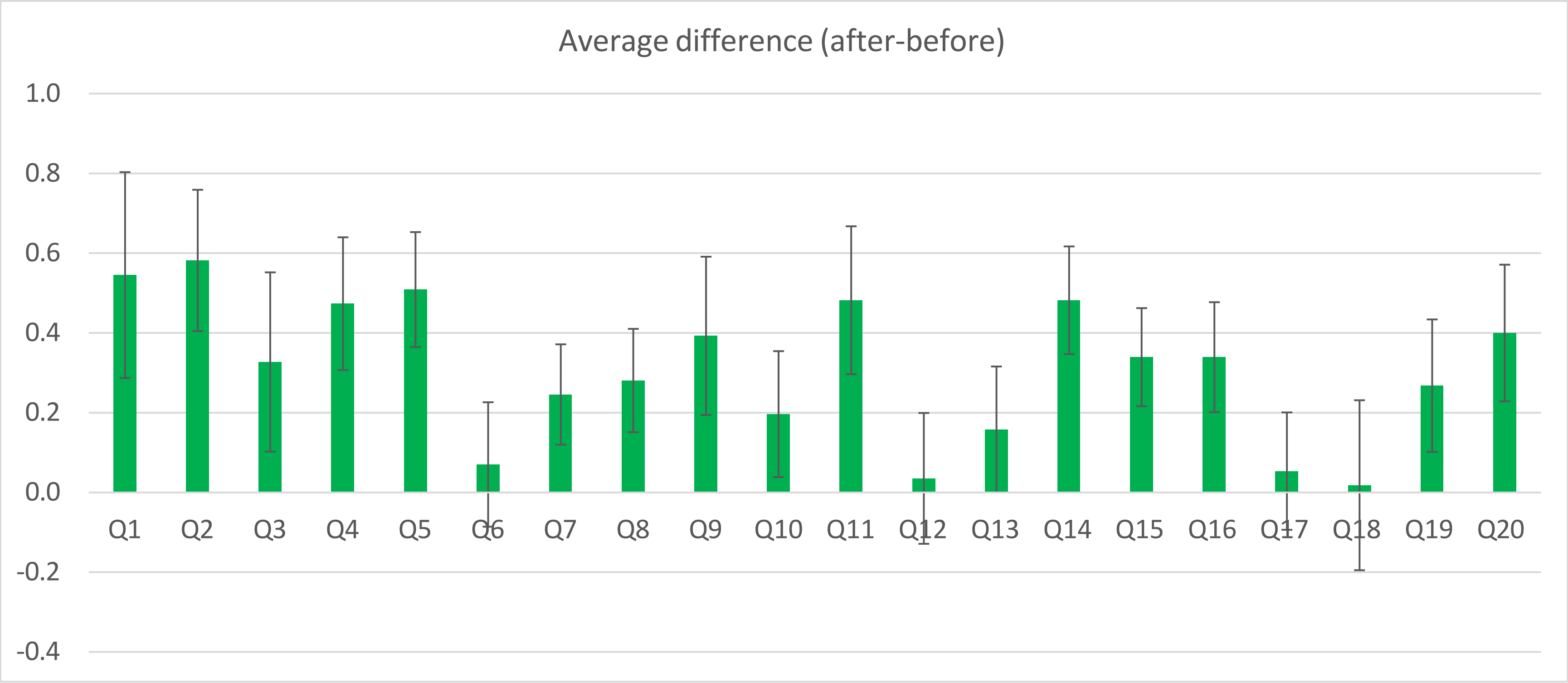


Figure 9. Differences in response ratings (after - before) for questions on survey. Error bars represent standard deviation of the mean.

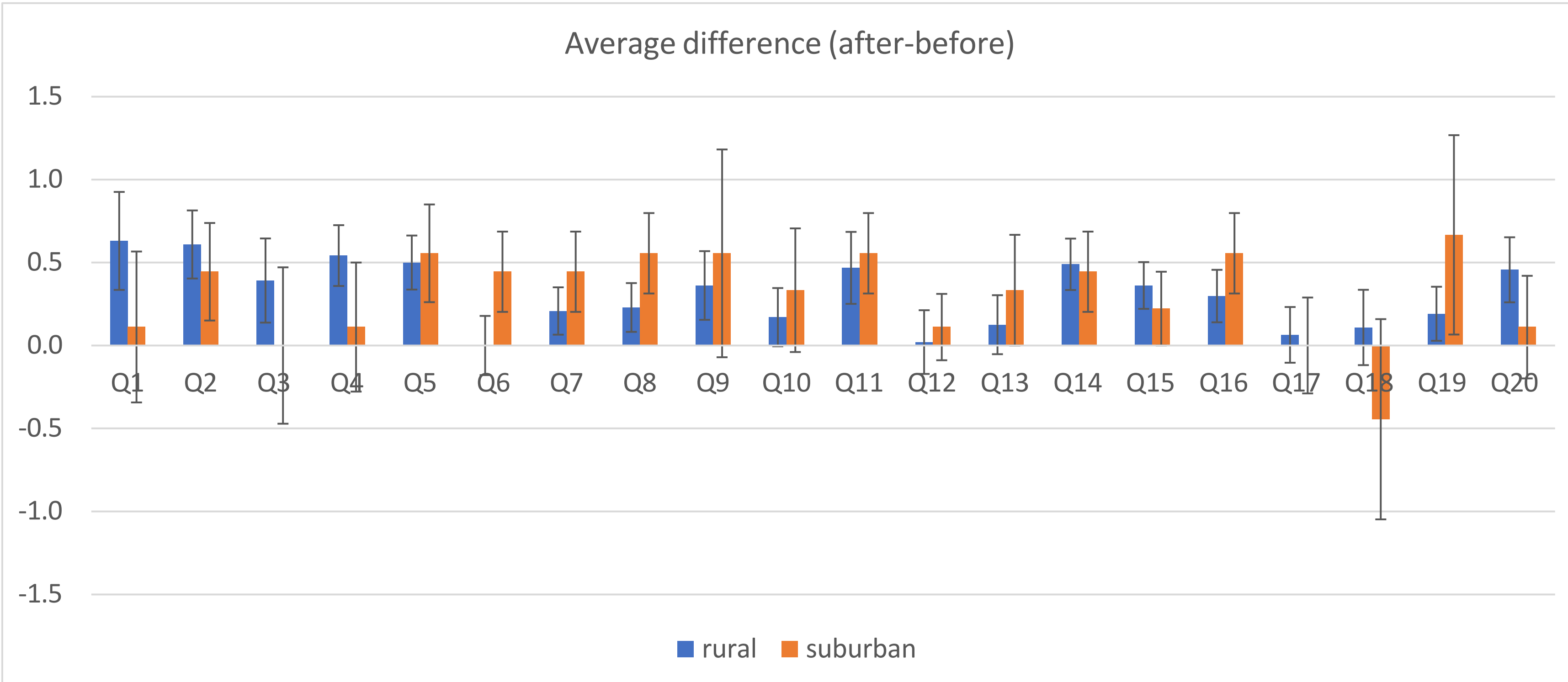


Figure 10. Differences in response ratings (after - before) for questions on survey grouped by rural and suburban respondents. Suburban respondents were from Grove City (n=9), and the rural group comprised all other respondents (n = 58-9 = 49). Error bars represent standard deviation of the mean.

Appendix A: Demographic survey

Demographics

Please tell us a little bit about yourself by answering the 20 questions below. If you do not wish to answer a question or statement, please select "prefer not to answer."

1. What is your gender identity?
   - ☐ Male
   - ☐ Female
   - ☐ Other
   - ☐ Prefer not to answer

2. Please indicate your age in the ranges below.
   - ☐ 40-49
   - ☐ 50-59
   - ☐ 60-69
   - ☐ 70-79
   - ☐ 80-89
   - ☐ 90+
   - ☐ Prefer not to answer

3. Please indicate your race/ethnicity: (Select all that apply.)
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African American
   - ☐ Hispanic or Latino
   - ☐ Native Hawaiian or Other Pacific Islander
   - ☐ White
   - ☐ Other
   - ☐ Prefer not to answer

4. What is the highest degree or level of school you have completed?
   - ☐ Middle, junior or high school - no degree
   - ☐ High school graduate or GED
   - ☐ Trade/Technical School or Certification Program
   - ☐ Some college, no degree
   - ☐ Associate's degree
   - ☐ Bachelor's degree
   - ☐ Master's degree
   - ☐ Doctoral degree
   - ☐ Prefer not to answer

5. What is your current employment situation? (Please select all that apply.)
   - ☐ Work (paid) part-time (less than 40 hours per week)
   - ☐ Work (paid) full-time (40 or more hours per week)
   - ☐ Work multiple (paid) part-time jobs
   - ☐ Have never been formally employed (paid for work)
   - ☐ Retired (do not work or volunteer)
   - ☐ Retired and Volunteer Part-time (20 hours or less per week)
   - ☐ Retired and Volunteer Full-time (more than 20 hours per week)
   - ☐ Not employed (under age 65)
   - ☐ Full-time Student
   - ☐ Disabled/ not able to work
   - ☐ Other
   - ☐ Prefer not to answer

6. Do you have a valid driver's license?
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

7. Do you own a working motor vehicle, such as a car, truck, or motorcycle?
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

8. I reply upon a vehicle to access services (e.g. grocery story, bank, etc.) in my community.
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

9. I would have to drive/ride at least 10 minutes to get to the town part of my community.
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

10. Which best describes you? (Select one)
    - ☐ I drive myself to locations in all situations
    - ☐ I and a friend/relative take turns driving to locations
    - ☐ I typically have a friend/relative who drives me to locations
    - ☐ I mostly use public transportation services to drive me to locations
    - ☐ I mostly use private transportation services to drive me to locations
    - ☐ I mostly walk to locations
    - ☐ Prefer not to answer

11. On average, how many trips do you make from your home to various locations each week? (Example, a trip to the grocery store and back is one trip.)
   - ☐ 0 to 5 trips a week
   - ☐ 6 to 10 trips a week
   - ☐ 11 to 15 trips a week
   - ☐ 16 to 20 trips a week
   - ☐ More than 20 trips a week
   - ☐ Prefer not to answer

12. Do you have regular and reliable access to the internet at your residence?
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

13. Do you own *and* know how to use a the internet on your computer or smartphone?
   - ☐ Yes
   - ☐ No
   - ☐ Prefer not to answer

14. If you drive, do you have a medical condition that influences your ability to drive safely at any time (day or night)?
   - ☐ Yes
   - ☐ No
   - ☐ Not applicable – I do not drive
   - ☐ Prefer not to answer

15. If you plan to continue driving in the future, do you think you may have a medical condition at some point that may influence your ability to drive safely at any time (day or night)?
   - ☐ Yes
   - ☐ No
   - ☐ Not applicable – I do not drive
   - ☐ Prefer not to answer

16. I am currently a regular driver for someone who cannot drive due to a health condition.
   - ☐ Yes
   - ☐ No
   - ☐ Not applicable – I do not drive
   - ☐ Prefer not to answer

17. I believe it is somewhat likely that at some point in the future, I may be a regular driver for someone who cannot drive due to their health condition.
   - ☐ Yes
   - ☐ No
   - ☐ Not applicable – I do not drive
   - ☐ Prefer not to answer

18. I am aware of the concept of an automated vehicle.
    - ☐ Yes
    - ☐ No
    - ☐ Prefer not to answer

19. I feel confident that I know what an automated vehicle is.
    - ☐ Yes
    - ☐ No
    - ☐ Prefer not to answer

20. Do you have any health conditions that influence your use of transportation or confidence to drive safely? If so, please select all that apply:
    - ☐ Physical (for example, unable to turn neck or maintain pressure on the brake or gas pedal)
    - ☐ Vision (for example, difficulty driving at night)
    - ☐ Hearing (for example, deafness)
    - ☐ Cognitive (for example, difficulty paying attention while driving)
    - ☐ Psychological (for example, anxiety in heavy traffic)
    - ☐ None of these
    - ☐ Prefer not to answer

Appendix B: Survey on Autonomous Vehicles

Note: This is the survey given to focus groups before the presentation. The same questions were then administered as Part 2 after the presentation.

PART 1

PLEASE READ: Automated vehicles refer to vehicles that *do not require a driver*. In other words, nobody needs to be in the driver's seat of the vehicle. Instead, the vehicle is programmed to go to select locations and uses GPS and sensors to achieve this. The rider in these vehicles do not have to do anything other than ride to their destination. This may include passengers who have a disability, as automated vehicles can be designed to be handicap accessible.

Automated vehicles are still in the development stage, so they are not yet available for purchase. However, as these vehicles become available to purchase, it is likely that they will first be owned by organizations and community services to provide transportation for community members.

It is critical to understand the concerns, needs, and preferences of persons who may someday use or be around automated vehicles. Your feedback will help those who develop and research these vehicles.

****

INSTRUCTIONS: Read each of the below statements and circle the number that best corresponds to your level of agreement with the statement. Your selected number may be any number between 1 and 7.

1 = Strongly Disagree 7 = Strongly Agree

1. I believe I would feel comfortable as a rider in an automated vehicle.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

2. I am comfortable with the idea of being in a vehicle on the road at the same time as an automated vehicle.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

3. I am comfortable with the idea of being a pedestrian on a sidewalk at the same time as an automated vehicle driving by.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

****

INSTRUCTIONS: Imagine that you are in a situation where you no longer drive and would have to rely on other transportation options. This may include automated vehicles.

Read each of the statements and respond as if you were in this situation and had access to an automated vehicle.

1 = Strongly Disagree ----- 7 = Strongly Agree.

USES FOR AN AUTOMATED VEHICLE

4. I would ride in an automated vehicle for *essential transportation needs only*. (Example: groceries, bank, appointments.)

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

5. I would ride in an automated vehicle for *casual needs* (Example: visiting a friend, going out to dinner).

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

<u>SAFETY</u> <u>ASPECTS OF USING AN AUTOMATED VEHICLE</u>

6. I would ride in an automated vehicle if I was first *assured that it is a safe and reliable transportation option by someone I personally know and trust.*

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

7. I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – with me *in person* so that I could ask questions.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

8. I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – via a video recording.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

9. I would ride in an automated vehicle if someone rode with me first in case I got nervous or had questions.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

10. I would ride in an automated vehicle if there was an option of providing a family member or friend with live updates of where I was throughout the ride.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

11. I would feel safe riding in an automated vehicle even when considering the driving of other people on the road at the same time.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

12. I would feel more comfortable riding in an automated vehicle if I knew I had some kind of control of the vehicle, such as access to an emergency break button.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

13. I would feel more comfortable riding in an automated vehicle if I knew I had access to live help. (Example: a call button that would connect me to an agent who could assist.)

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

PROVIDERS: ORGANIZATIONS AND SERVICES THAT WOULD PROVIDE AUTOMATED VEHICLE AS A FORM OF TRANSPORTATION.

14. I would ride in an automated vehicle if it was provided *from a transportation service.* (Example: Uber, Lyft, taxi, community bus/shuttle, etc.).

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

15. I would ride in an automated vehicle if it was provided *or arranged by an individual I trust,* such as a family member or friend.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

16. I would ride in an automated vehicle if it was provided *from an organization* that I trust (Example: a hospital, church, community business).

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

FEE/PAY: USE OF AN AUTOMATED VEHICLE FROM A PROVIDER

17. I would use an automated vehicle service *only if there was no fee*. (Free.)

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

18. I would use an automated vehicle service *if the cost was about the same as* using a shuttle, bus, taxi, or Uber/Lyft.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

19. I would use an automated vehicle service *even if it was slightly more expensive* than the cost of a shuttle, bus, taxi, or Uber/Lyft.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

20. I would use an automated vehicle service because I do not want to ride with a stranger.

Strongly Disagree Neutral Strongly agree

1. 2. 3. 4. 5. 6. 7.

END HERE.

Appendix C: Responses to first survey (before presentation).

		disagree		neutral			agree					
	First survey (before presentation)	1	2	3	4	5	6	7	n	avg	std dev	SDM
Q1	I believe I would feel comfortable as a rider in an automated vehicle.	28%	9%	5%	26%	18%	7%	7%	57	3.46	1.95	0.26
Q2	I am comfortable with the idea of being in a vehicle on the road at the same time as an automated vehicle.	23%	14%	9%	26%	12%	9%	7%	57	3.46	1.89	0.25
Q3	I am comfortable with the idea of being a pedestrian on a sidewalk at the same time as an automated vehicle driving by.	26%	9%	7%	19%	12%	18%	9%	57	3.70	2.10	0.28
Q4	I would ride in an automated vehicle for essential transportation needs only. (Example: groceries, bank, appointment.)	24%	5%	5%	22%	21%	12%	10%	58	3.88	2.03	0.27
Q5	I would ride in an automated vehicle for casual needs. (Example: visiting a friend, going out to dinner.)	28%	7%	7%	29%	14%	7%	9%	58	3.50	1.96	0.26
Q6	I would ride in an automated vehicle if I was first assured that it is a safe and reliable transportation option by someone I personally know and trust.	14%	5%	2%	28%	16%	24%	12%	58	4.47	1.88	0.25
Q7	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – with me in person so that I could ask questions.	16%	0%	5%	33%	7%	24%	16%	58	4.50	1.92	0.25
Q8	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – via a video recording.	21%	2%	5%	28%	17%	16%	12%	58	4.14	1.98	0.26
Q9	I would ride in an automated vehicle if someone rode with me first in case I got nervous or had questions.	22%	5%	2%	22%	9%	22%	17%	58	4.26	2.19	0.29
Q10	I would ride in an automated vehicle if there was an option of providing a family member or friend with live updates of where I was throughout the ride.	19%	3%	2%	31%	10%	17%	17%	58	4.31	2.05	0.27
Q11	I would feel safe riding in an automated vehicle even when considering the driving of other people on the road at the same time.	21%	9%	12%	26%	12%	9%	11%	57	3.68	1.94	0.26
Q12	I would feel more comfortable riding in an automated vehicle if I knew I had some kind of control of the vehicle, such as access to an emergency brake button.	11%	2%	7%	19%	7%	21%	33%	57	5.07	1.98	0.26
Q13	I would feel more comfortable riding in an automated vehicle if I knew I had access to live help. (Example: a call button that would connect me to an agent who could assist.)	16%	4%	0%	19%	18%	12%	32%	57	4.85	2.11	0.28
Q14	I would ride in an automated vehicle if it was provided from a transportation service. (Example: Uber, Lyft, taxi, community bus/shuttle, etc.)	26%	2%	11%	25%	7%	18%	12%	57	3.86	2.12	0.28
Q15	I would ride in an automated vehicle if it was provided or arranged by an individual I trust, such as a family member or friend.	19%	12%	4%	26%	7%	18%	14%	57	3.98	2.09	0.28
Q16	I would ride in an automated vehicle if it was provided from an organization that I trust. (Example: hospital, church, community business.)	21%	3%	3%	29%	14%	17%	12%	58	4.12	2.00	0.26

		disagree		neutral			agree					
	First survey (before presentation)	1	2	3	4	5	6	7	n	avg	std dev	SDM
Q17	I would use an automated vehicle service because I do not want to inconvenience anyone for a ride	19%	5%	2%	28%	12%	21%	14%	58	4.26	2.03	0.27
Q18	I would use an automated vehicle service if the cost was about the same as using a shuttle, bus, taxi, or Uber/Lyft.	22%	3%	5%	43%	9%	7%	10%	58	3.74	1.87	0.25
Q19	I would use an automated vehicle service even if it was slightly more expensive than the cost of a shuttle, bus, taxi, or Uber/Lyft.	22%	3%	2%	33%	14%	14%	12%	58	4.02	2.00	0.26
Q20	I would use an automated vehicle service only if there was no fee. (Free.)	28%	2%	11%	33%	14%	7%	5%	57	3.46	1.83	0.24

n = number of nonblank responses to question
SDM = standard deviation of the mean (or standard error) = (std dev) / sqrt (n)

Appendix D: Responses to second survey (after presentation).

		disagree		neutral			agree					
	First survey (before presentation)	1	2	3	4	5	6	7	n	avg	std dev	SDM
Q1	I believe I would feel comfortable as a rider in an automated vehicle.	21%	11%	5%	16%	11%	25%	11%	56	4.02	2.14	0.29
Q2	I am comfortable with the idea of being in a vehicle on the road at the same time as an automated vehicle.	20%	11%	5%	21%	7%	27%	9%	56	4.02	2.07	0.28
Q3	I am comfortable with the idea of being a pedestrian on a sidewalk at the same time as an automated vehicle driving by.	20%	14%	4%	16%	16%	20%	11%	56	3.96	2.09	0.28
Q4	I would ride in an automated vehicle for essential transportation needs only. (Example: groceries, bank, appointment.)	19%	5%	5%	18%	16%	21%	16%	57	4.32	2.10	0.28
Q5	I would ride in an automated vehicle for casual needs. (Example: visiting a friend, going out to dinner.)	25%	5%	4%	23%	12%	23%	9%	57	3.96	2.09	0.28
Q6	I would ride in an automated vehicle if I was first assured that it is a safe and reliable transportation option by someone I personally know and trust.	18%	4%	5%	21%	9%	26%	18%	57	4.49	2.08	0.28
Q7	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – with me in person so that I could ask questions.	14%	4%	9%	21%	4%	23%	26%	57	4.70	2.10	0.28
Q8	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – via a video recording.	16%	4%	9%	26%	5%	26%	14%	57	4.37	1.99	0.26
Q9	I would ride in an automated vehicle if someone rode with me first in case I got nervous or had questions.	18%	4%	7%	16%	11%	16%	29%	56	4.61	2.20	0.29
Q10	I would ride in an automated vehicle if there was an option of providing a family member or friend with live updates of where I was throughout the ride.	18%	2%	5%	27%	11%	14%	23%	56	4.46	2.09	0.28
Q11	I would feel safe riding in an automated vehicle even when considering the driving of other people on the road at the same time.	18%	5%	13%	21%	16%	16%	11%	56	4.04	1.94	0.26
Q12	I would feel more comfortable riding in an automated vehicle if I knew I had some kind of control of the vehicle, such as access to an emergency brake button.	14%	2%	5%	14%	11%	25%	30%	57	4.98	2.07	0.27
Q13	I would feel more comfortable riding in an automated vehicle if I knew I had access to live help. (Example: a call button that would connect me to an agent who could assist.)	16%	2%	5%	18%	7%	23%	30%	57	4.86	2.13	0.28
Q14	I would ride in an automated vehicle if it was provided from a transportation service. (Example: Uber, Lyft, taxi, community bus/shuttle, etc.)	21%	4%	9%	16%	14%	18%	19%	57	4.28	2.17	0.29
Q15	I would ride in an automated vehicle if it was provided or arranged by an individual I trust, such as a family member or friend.	19%	4%	9%	21%	12%	18%	18%	57	4.26	2.09	0.28
Q16	I would ride in an automated vehicle if it was provided from an organization that I trust. (Example: hospital, church, community business.)	19%	2%	9%	21%	7%	23%	19%	57	4.40	2.13	0.28
Q17	I would use an automated vehicle service because I do not want to inconvenience anyone for a ride	25%	4%	5%	14%	11%	23%	19%	57	4.28	2.27	0.30

		disagree		neutral			agree					
	First survey (before presentation)	1	2	3	4	5	6	7	n	avg	std dev	SDM
Q18	I would use an automated vehicle service if the cost was about the same as using a shuttle, bus, taxi, or Uber/Lyft.	27%	4%	11%	29%	7%	7%	16%	56	3.71	2.11	0.28
Q19	I would use an automated vehicle service even if it was slightly more expensive than the cost of a shuttle, bus, taxi, or Uber/Lyft.	21%	0%	9%	20%	14%	23%	13%	56	4.25	2.06	0.27
Q20	I would use an automated vehicle service only if there was no fee. (Free.)	25%	5%	7%	22%	13%	16%	11%	55	3.84	2.10	0.28

n = number of nonblank responses to question
SDM = standard deviation of the mean (or standard error) = (std dev) / sqrt (n)

Appendix E: Changes in responses from first to second survey.

	Change is response (response 2 – response 1)	n	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	avg	std dev	SDM
Q1	I believe I would feel comfortable as a rider in an automated vehicle.	55	1.8%	0.0%	1.8%	3.6%	1.8%	1.8%	45.5%	18.2%	14.5%	7.3%	0.0%	1.8%	1.8%	0.55	1.91	0.26
Q2	I am comfortable with the idea of being in a vehicle on the road at the same time as an automated vehicle.	55	0.0%	0.0%	0.0%	0.0%	3.6%	9.1%	49.1%	12.7%	18.2%	5.5%	0.0%	1.8%	0.0%	0.58	1.32	0.18
Q3	I am comfortable with the idea of being a pedestrian on a sidewalk at the same time as an automated vehicle driving by.	55	1.8%	0.0%	1.8%	1.8%	3.6%	1.8%	52.7%	18.2%	10.9%	5.5%	0.0%	1.8%	0.0%	0.33	1.67	0.22
Q4	I would ride in an automated vehicle for essential transportation needs only. (Example: groceries, bank, appointment.)	57	0.0%	0.0%	0.0%	0.0%	3.5%	10.5%	50.9%	15.8%	12.3%	3.5%	3.5%	0.0%	0.0%	0.47	1.26	0.17
Q5	I would ride in an automated vehicle for casual needs. (Example: visiting a friend, going out to dinner.)	57	0.0%	0.0%	0.0%	0.0%	1.8%	7.0%	57.9%	10.5%	17.5%	5.3%	0.0%	0.0%	0.0%	0.51	1.09	0.14
Q6	I would ride in an automated vehicle if I was first assured that it is a safe and reliable transportation option by someone I personally know and trust.	57	0.0%	0.0%	1.8%	5.3%	0.0%	7.0%	57.9%	19.3%	8.8%	0.0%	0.0%	0.0%	0.0%	0.07	1.18	0.16
Q7	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – with me in person so that I could ask questions.	57	0.0%	0.0%	0.0%	1.8%	1.8%	3.5%	68.4%	15.8%	5.3%	3.5%	0.0%	0.0%	0.0%	0.25	0.95	0.13
Q8	I would ride in an automated vehicle if a vehicle technician thoroughly went over the main features of the vehicle – including safety features – via a video recording.	57	0.0%	0.0%	0.0%	1.8%	1.8%	3.5%	66.7%	15.8%	7.0%	3.5%	0.0%	0.0%	0.0%	0.28	0.98	0.13
Q9	I would ride in an automated vehicle if someone rode with me first in case I got nervous or had questions.	56	0.0%	0.0%	0.0%	3.6%	1.8%	8.9%	51.8%	21.4%	5.4%	3.6%	0.0%	1.8%	1.8%	0.39	1.49	0.20
Q10	I would ride in an automated vehicle if there was an option of providing a family member or friend with live updates of where I was throughout the ride.	56	0.0%	0.0%	0.0%	3.6%	1.8%	7.1%	66.1%	8.9%	5.4%	7.1%	0.0%	0.0%	0.0%	0.20	1.18	0.16
Q11	I would feel safe riding in an automated vehicle even when considering the driving of other people on the road at the same time.	56	0.0%	0.0%	1.8%	1.8%	0.0%	1.8%	60.7%	19.6%	7.1%	1.8%	3.6%	1.8%	0.0%	0.48	1.39	0.19
Q12	I would feel more comfortable riding in an automated vehicle if I knew I had some kind of control of the vehicle, such as access to an emergency brake button.	57	0.0%	0.0%	0.0%	3.5%	5.3%	15.8%	49.1%	17.5%	5.3%	1.8%	1.8%	0.0%	0.0%	0.04	1.24	0.16
Q13	I would feel more comfortable riding in an automated vehicle if I knew I had access to live help. (Example: a call button that would connect me to an agent who could assist.)	57	0.0%	0.0%	0.0%	3.5%	1.8%	10.5%	63.2%	7.0%	10.5%	1.8%	1.8%	0.0%	0.0%	0.16	1.19	0.16
Q14	I would ride in an automated vehicle if it was provided from a transportation service. (Example: Uber, Lyft, taxi, community bus/shuttle, etc.)	56	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	60.7%	16.1%	8.9%	7.1%	0.0%	0.0%	0.0%	0.48	1.01	0.13

	Change is response (response 2 – response 1)	n	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	avg	std dev	SDM
Q15	I would ride in an automated vehicle if it was provided or arranged by an individual I trust, such 56as a family member or friend.	56	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	57.1%	16.1%	12.5%	1.8%	0.0%	0.0%	0.0%	0.34	0.92	0.12
Q16	I would ride in an automated vehicle if it was provided from an organization that I trust. (Example: hospital, church, community business.)	56	0.0%	0.0%	1.8%	0.0%	0.0%	5.4%	62.5%	16.1%	12.5%	1.8%	0.0%	0.0%	0.0%	0.34	1.03	0.14
Q17	I would use an automated vehicle service because I do not want to inconvenience anyone for a ride	56	0.0%	0.0%	0.0%	5.4%	1.8%	8.9%	58.9%	17.9%	5.4%	1.8%	0.0%	0.0%	0.0%	0.05	1.10	0.15
Q18	I would use an automated vehicle service if the cost was about the same as using a shuttle, bus, taxi, or Uber/Lyft.	55	0.0%	0.0%	0.0%	9.1%	1.8%	10.9%	60.0%	7.3%	1.8%	7.3%	0.0%	0.0%	1.8%	0.02	1.58	0.21
Q19	I would use an automated vehicle service even if it was slightly more expensive than the cost of a shuttle, bus, taxi, or Uber/Lyft.	56	0.0%	0.0%	0.0%	1.8%	3.6%	8.9%	60.7%	8.9%	12.5%	1.8%	0.0%	1.8%	0.0%	0.27	1.24	0.17
Q20	I would use an automated vehicle service only if there was no fee. (Free.)	55	0.0%	0.0%	0.0%	3.6%	0.0%	9.1%	56.4%	9.1%	14.5%	7.3%	0.0%	0.0%	0.0%	0.40	1.27	0.17

n = number of nonblank responses to question

SDM = standard deviation of the mean (or standard error) = (std dev) / sqrt (n)