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Transit IDEA Program

Connected and Automated Parking Feasibility – A Pilot Study

Final Report for
Transit IDEA Project 95

Prepared by:
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Maryland Transit Administration

November 2021

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Washington, DC 20001

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IDEA Program Final Report

Transit IDEA J-04/IDEA 95

Prepared for the IDEA Program

Transportation Research Board

The National Academies

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Acknowledgements

The project team would like to acknowledge the contributions of the Expert Advisory Panel members, Gary Hsueh (CHS Consulting Group), Louis Sanders (Ayers Electronic Systems, LLC), Frank Ching (Los Angeles Metro), and Angela Miller (Deloitte). Also, we would like to acknowledge the assistance and guidance by the TRB and the National Academy of the Sciences, Engineering, and Medicine representatives. Finally, this work would not have been possible without the support and funding from the Transit IDEA J-04 Program.

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EXECUTIVE SUMMARY

The *Connected and Automated Parking Feasibility – A Pilot Study* is the first pilot study in the United States to test the benefits transit agencies may obtain from deploying automated parking technology. Running from March 2019 to June 2021, the project involved operating low-speed automated vehicles in the parking lots of two Maryland Area Regional Commuter (MARC) train stations in suburban Maryland. The goal of the pilot was to introduce the automated vehicles to transit riders and analyze the extent to which exposure to the vehicles altered respondents' enthusiasm for autonomous vehicles. The relationship between automated vehicle use and mass transit was examined to test if automated vehicles could increase ridership, increase commuter safety, and increase revenue for transit agencies.

The pilot study was conducted jointly by the Maryland Department of Transportation Maryland Transit Administration (MDOT MTA), and STEER Tech, a company whose software kit enables vehicles to drive and park autonomously within mapped parking lots and garages (equivalent to SAE Level 4 autonomous driving). Equipped with STEER Tech, the Connected and Automated Vehicle (CAV) can drop off a passenger at the entrance to the train station and then park itself in a dedicated section of the parking lot. The passenger can then use their smartphone to summon the vehicle to pick them up upon arrival at the station.

The pilot's initial location was at MDOT MTA's MARC Dorsey station. During Phase, STEER Tech digitally mapped the MARC Dorsey station and conducted closed-course testing in the station's parking facility. Phase 2 involved off-peak, mixed traffic testing. Phase 2 began at the MARC Dorsey station and would be moved to another MARC station (Odenton), due to COVID-

FIGURE 1 The STEER Automated Vehicle at the MARC Dorsey Station

19 and the need to select a station that still had ridership. Phase 3 was held entirely at the MARC Odenton station and involved mixed traffic testing during peak travel hours.

Despite significant disruptions presented by COVID-19, data collected from the pilot supports the following hypotheses:

- Automated parking technology is feasible for transit agencies to deploy at passenger parking facilities;
- Automated parking technology could allow transit agencies to expand parking capacity by up to 20%, increasing parking revenue and reducing capital costs;
- Most respondents said they would be comfortable using STEER Tech's CAV technology, and that its availability made it more likely that they would choose to ride commuter rail.

Four surveys of MARC commuter rail riders were conducted during the pilot. Nearly 60% of respondents (n = 141) stated that they would utilize CAV technology if it was available at their transit station. Over 23% of respondents (n = 160) stated that they would ride transit more often if the parking lot was less full or if they did not have to park their own car. Notably, other MARC stations have more crowded parking facilities than Dorsey, suggesting potentially greater potential benefits at other stations with higher parking demand.

Relatively few responses were collected for certain survey questions due to the disruption of the COVID-19 pandemic. With the caveat of low sample sizes, 74% of respondents said that an automated vehicle that picked them up at the station would make them feel safer, and almost half of the respondents said they would commute on transit more often if they could more accurately predict how long it would take them to park. Roughly 45% of respondents stated that seeing STEER Tech in operation had increased their interest in autonomous vehicle technology.

Further study is necessary to explore the potential that CAVs offer transit agencies, particularly because this pilot coincided with COVID-19. However, the findings of the *Connected and Automated Parking Feasibility Pilot* support hypotheses that CAVs can benefit transit agencies, both by attracting additional riders to transit and by expanding parking capacity at rail stations without requiring a substantial capital investment.

INTRODUCTION

The objective of this *Connected and Automated Parking Feasibility Pilot* at the MARC Dorsey and MARC Odenton Stations is to develop a rapid assessment of Maryland's infrastructure readiness for Connected Automated Vehicle (CAV) parking while deploying innovative automated solutions to increase ridership, improve transit safety, and increase transit revenue. Increased ridership is particularly influenced by commuters' three main factors to select a travel mode: convenience, time, and money. By assessing the readiness for CAVs and then potentially implementing them as a result of positive findings, the Maryland Department of Transportation Maryland Transit Administration (MDOT MTA), in partnership with STEER Tech, can improve all three main factors that influence commuters, improving overall rail services.

IDEA PRODUCT

Developed by automotive software company STEER Tech, STEER is a Level 4 automated parking technology that is installed onto new and existing cars by adding a small computer and camera to the vehicles. STEER enables cars to drive and park autonomously within mapped parking lots and garages. When a user pulls up the transit station, they can drop themselves off at the curb, send their car to park for them via the STEER app, and leave to catch the train. When they return, they can summon their car back to them and their car will drive itself to meet the user at the pickup point (see Figure 2).

FIGURE 2 How STEER Works

STEER Tech is headquartered in Maryland and works closely with the Maryland Department of Transportation and its divisions, primarily the MDOT Motor Vehicle Administration (MVA) and MDOT MTA, to accelerate MDOT's goal of modernizing the state's transportation systems. STEER Tech has played a vital role in assisting with the creation of the CAV permitting process which enables companies such as STEER Tech to test their autonomous vehicles on public roadways. This permitting process is innovative and attracts other CAV technology companies to the state.

MDOT's eagerness to collaborate with emerging tech companies and the state's expansive public transportation networks made Maryland the prime location to test the integration of AVs at transit sites and assess the state's preparedness for such integrations.

Through a phased integration of STEER's automated technology at two transit sites, STEER was able to assess Maryland's current readiness for similar CAV technologies. The findings from this assessment can be used to better prepare MDOT and other transportation agencies for the coming expanded use of vehicles with automated technology and eventually, the integration of fully autonomous vehicles on public and private roadways.

CONCEPT AND INNOVATION

The *Connected and Automated Parking Feasibility Pilot* surveyed commuter behavior with the goal to provide MDOT MTA with the data necessary to evaluate CAV technology to reduce pain points for commuters when parking. The pilot initially took place at MDOT MTA's MARC Dorsey Station located in Howard County, Maryland, but was later relocated to MDOT MTA's MARC Odenton Station, located in Anne Arundel County, Maryland due to COVID-19 related issues (see the COVID-19 Complications section). The MARC Dorsey Station is on the MARC Camden commuter rail line connecting Baltimore to Washington, DC. The MARC Odenton Station is on the MARC Penn commuter rail line connecting Baltimore up to Perryville to Washington, D.C.

In the United States, motorists spend an average of 17 hours per year searching for parking spots, according to a 2017 study conducted by traffic analytics provider Inrix *(1)*. The study found that those hours cost each motorist an average of $345 in wasted time, fuel, and emissions. MDOT MTA has multiple parking facilities that are at or above capacity such that commuters spend time searching for parking spaces to a point that can negatively impact their decision to take the commuter rail or rapid transit. Additionally, at various MDOT MTA parking facilities, commuters

can spend over ten minutes walking to MARC stations due to having to park over a half-mile away from the stations. There are also cost burdens associated with many overutilized MDOT parking facilities due to the need to lease land from adjacent housing or businesses to meet the increasing parking demand.

According to the Howard County Chamber of Commerce, the county is one of the fastest-growing in the state - its population has increased 34% in the past ten years. The county is also increasingly home to more cybersecurity and technology companies, but the resulting traffic congestion is a concern for state and county planners. Since innovative technology companies continue to move to the region, connected and automated vehicles are a potential relief to traffic congestion and parking pain points. CAVs also pose a possible solution to eliminate the over 50,000 accidents and 580 deaths that occur in parking lots a year.

Connected and automated vehicles also pose a possible solution to eliminate the over 50,000 accidents and 580 deaths that occur in parking lots a year.

Maryland is the first state to test Level 4 CAV parking technology and STEER Tech is the first company in Maryland to be issued a CAV permit. The permit also covers exploration into smart city and automated vehicle technologies, including STEER Tech's Automated Valet Parking (AVP) technology, which will transform ordinary cars into self-parking cars. Technological integration will permit Howard County to be the first region in the country to be built for self-parking cars.

The *Connected and Automated Parking Feasibility Pilot* will help Maryland prepare commuter parking infrastructure for CAV technology. As part of this pilot, MDOT MTA assessed infrastructure improvements needed to deploy CAV and tested AVP technology in phases to determine if AVP will affect first and last-mile commuter behavior, result in time and cost savings for commuters, increase ridership by eliminating parking pain points, increase commuter safety, and increase revenue for MDOT MTA. The agency has overcrowded commuter parking lots on both the MARC Camden Line and the MARC Penn Line due to heavy commuter traffic between Baltimore and Washington, DC. The peak rush hours create traffic congestion and commuter pain points. Efficiencies in parking will increase transit ridership, improve public safety by minimizing parking accidents in commuter parking lots and bolster public acceptance of connected and automated vehicles, all of which will impact the future transportation landscape.

MDOT MTA already recommends parking management programs such as reserved carpool/vanpool parking, parking information systems, and reduced parking ratios, but the agency envisions AVP will further provide real-time assessments coupled with increased time and cost savings for first and last-mile transportation, demonstrating parking efficiencies for future planning of commuter parking lots with AVP.

Since many MDOT MTA parking facilities are at or near capacity, the deployment of AVP in this pilot experimented with improving parking efficiency by mapping said parking facilities and testing AVP in a phased approach - first, in a closed lot with no public access, surveying the results, and then moving to a public lot with mixed uses during peak and off-peak commuting periods to observe commuter behavior, driving patterns, and efficiency concerning the design of the parking spaces. For this pilot, underutilized stations were selected because it was important to the stakeholders to not cause additional perturbation to the environment of the busier stations.

AVP technology is most promising in its potential for increasing parking lot and garage capacities. Past studies have shown, and this pilot corroborated, that AVP technology can park cars closer together (since drivers aren't needed to open or close doors), allowing for as much as a 20% increase in the number of vehicles that can be accommodated in the same space. Furthermore, the convenience of an automated parking valet will positively impact commuter behavior and increase ridership if the former parking pain point (hunting for a parking spot and then walking a long distance to the station from that spot) is eliminated.

To accomplish increased ridership, improved transit safety, and increased transit revenue by implementing CAV parking, MDOT MTA focused on the three objectives below by analyzing data collected both before and after the pilot and comparing it against key performance indicators (KPIs):

1) **Demonstrate Increased Ridership:**
   a) Testing AVP technology from STEER Tech will demonstrate the ease of the curbside drop-off/pick-up method to/from station entrances. Currently, commuters in overcrowded lots might walk upwards of ten minutes from the parking lot to station entrances.
   b) Studies indicate that AVP will increase parking space by up to 20% by eliminating the need to open or close doors. This will increase capacity in overcrowded lots, allowing more commuters to travel to and from high-demand stations and thereby increase ridership.

2) **Improve Transit Safety:**
    a) Commuters often park long distances from stations, and during off-peak hours or early-morning/after-dark periods, some commuters - especially women - are concerned about safety walking to and from their vehicles. STEER Tech's AVP technology has the potential to reduce safety concerns by refocusing security (CCTV, call boxes, police patrols, etc.) onto centralized pick-up/drop-off locations, increasing commuters' confidence in safety.
    b) Efficiencies realized in parking spaces will increase vehicle safety. In an AVP lot, vehicles are parked closer together, which reduces hidden spaces exploited for vandalism and car theft.
    c) Parking lot accidents with pedestrians and property damage are some of the largest comprehensive vehicle insurance claims. Approximately 84% of all low-speed collision body damage occurs in parking lots. Since AVP will reduce pedestrian traffic in parking lots and reduce human error in parking, it will reduce overall claims for incidents. This will improve commuter safety and satisfaction at transit facilities.
3) **Increase Transit Revenue:**
    a) Removing commuter pain points with parking, increasing convenience and ease of use, decreasing overall trip time, and improving safety will provide a higher quality traveling experience for commuters and will attract more ridership from station "catchment areas," which will in turn increase transit revenue.
    b) AVP as a new convenience service will assess a fee for access to an automated parking valet service, thus increasing transit revenue.
    c) Parking efficiencies assessed with the pilot will provide MDOT MTA with traffic pattern and capacity information which will be monetized for increased transit revenue.

INVESTIGATION

Before the phased integration of STEER's autonomous vehicle at the MARC Dorsey station and later, MARC Odenton station, the STEER team met with various state safety agencies to conduct emergency response planning and teach safety protocols that directly relate to emergency personnel. The STEER team also worked with MDOT MTA and MDOT MVA to obtain autonomous vehicle testing permits that covered the MARC Dorsey commuter lot and, later, the MARC Odenton commuter lot.

Prior to and during the CAV testing, the MDOT MTA and STEER Team developed communication outreaches for various target audiences that were successful in reaching a wide group of Maryland's MARC commuters. Communications included informative signage at the stations and posted signage in the testing lots (see Figure 3), email communication via the MTA's MARC train commuter mailing list, and website communications via a website designed specifically for this pilot.

FIGURE 3 Informative Signage

Assessing the commuter's knowledge and opinion of CAV technologies was an important aspect of the project so consistent communication was imperative to gathering feedback from commuters. Four surveys that evaluated commuter knowledge of CAV technology and the commuter's experience with the STEER vehicles were distributed throughout the entirety of the project.

The first survey was distributed during the Pre-Deployment phase to create a baseline of unbiased responses particularly from riders who have never experienced an automated vehicle technology. One survey was then consequently distributed during each of the three remaining phases of the project to further

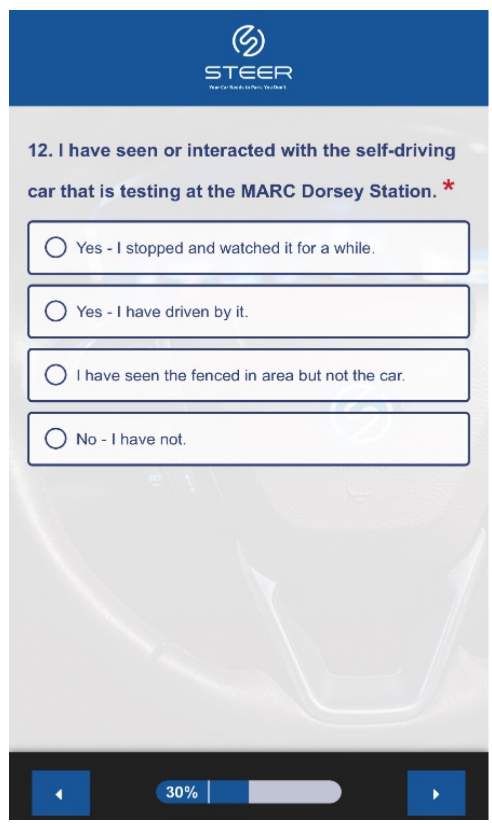


FIGURE 4 Example Survey Question

assess the commuter's experience and provide an outlet for feedback. The results of these surveys can be found under the "Findings" section of this report.

The *Connected and Automated Parking Feasibility Pilot* consisted of one preparation phase and three testing phases referred to as Phases 1 - 3. Each testing phase lasted four weeks long. Testing was undertaken by STEER CAV test operators. All test operators are pre-qualified and trained to operate autonomous vehicles. Test operators are trained on safety procedures to be followed on-site and have a set test plan for execution each day.

Phase 1
Closed Course

- Recreate scenarios in a controlled environment
- No interaction with pedestrians or other drivers
- Able to provide sufficient realism to safely test scenarios to completion
- Builds scenario confidence before transitioning to a live, open course

Phase 2
Off-Peak Hours

- More realistic testing environment
- Limited interaction with pedestrians and other drivers
- Able to test planned scenarios with the potential addition of organic obstacles
- Increased exposure of the automated vehicle to commuters

Phase 3
Peak Hours

- Live, dynamic testing environment
- Increased probability of unaccounted for scenarios to occur which allows for extensive, realistic data to be collected
- Highest potential for commuter awareness and increased comfort with CAVs through direct interaction

FIGURE 5 Phase Details

To understand the testing results in this report, a full valet is defined as the car autonomously starting at the drop-off zone, driving, and completing a parking maneuver. A full summon is defined as the car starting in the spot which it parked in, driving to the user location, and "picking up" the user. Point-to-point driving is defined as scenarios where the car is driving autonomously but does not necessarily execute a parking maneuver.

TESTING SCENARIOS

STEER has designed and executed hundreds of structured tests that cover a variety of use cases and emulate real-world parking lot scenarios. Internally, STEER's expansive library of scenarios is used to validate the system's core behavioral skills including parking, path following, object detection, intersection logic, collision avoidance, and more. STEER Test team is continuously finding and testing edge-case scenarios and deliberately challenging our system with the intent of finding its limits and identifying areas of improvement.

For the purposes of this project, our team focused on executing structured tests using our most tried and tested scenarios on new turf— commuter parking lots. The first phase of testing was closed course, where structured tests are put to practice with expected results. This allows testing under a wide variety of conditions and factors like weather, road conditions, glare, and assess the automated vehicle in the target environment for stability, vehicle control, safety engagements, and other dynamic control conditions without putting public commuter traffic or vehicles at risk. Subsequently, in the open course phase, these tests are expanded to cover traffic patterns, human interaction and dynamics associated with non-AV vehicles.

To ensure informative results, priority is given to scenarios that the vehicle would realistically face in a commuter parking lot. For complete coverage and to remove dependency from any implicit assumptions, tests are conducted for a variety of factors including localization, collision avoidance, and interactions with pedestrians and other road users. This phase also allows for testing compounding of failure scenarios and cascading concerns together that can exacerbate and diminish commuter patron experience, on a smaller volume of commuter traffic. The third phase, open course testing in peak hours, is the ultimate testing for commuter parking lots. This allows expanding testing of scenarios under stress, under time sensitivity of public commuters and real-world scenarios in real world timelines. Any compounding of failures here will require rapid resolution to avoid large scale disruption.

Scenario Categories

Scenarios are categorized by the core behavioral skill they aim to test. These categories include:

1. Collision Avoidance– Interactions with static and dynamic objects
2. Pedestrian Interactions– Interactions with humans

3. Road User Interactions– Interactions with other human or autonomous drivers on the road (other cars, cyclists, motorcyclists).
4. Localization– Parking and path following
5. Fault Response– Response to system faults (loss of network connectivity, mechanical failure, etc.)
6. User Experience– Ability to satisfy user expectations

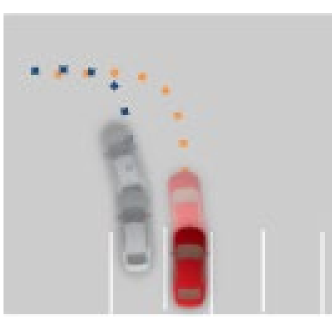
Each base scenario has an endless number of variations and can be tested in a variety of environments– further changing the scenario. See examples below.

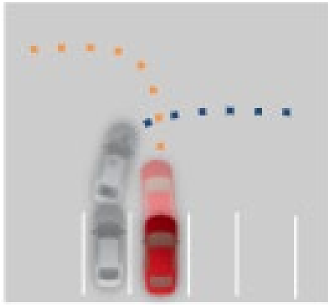
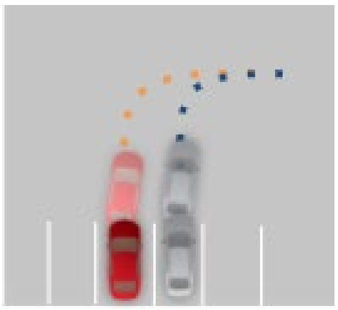
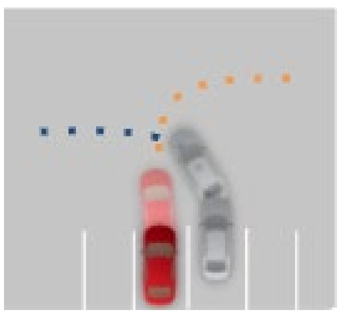
Sample Scenarios

Collision Avoidance - Sample Base Scenario

Scenario Description	Scenario Goal
While a STEER car autonomously summons out of its parking space, a human-driven car in a neighboring parking space leaves at the same time.	The STEER car should yield for the human-driven car and continue its mission once the path is clear. The STEER car must avoid collision with any obstacle.

Collision Avoidance - Sample Variations

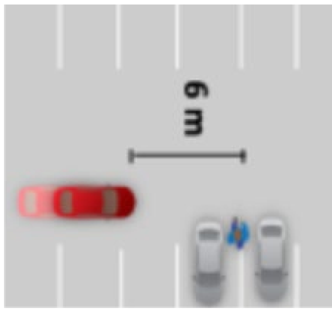
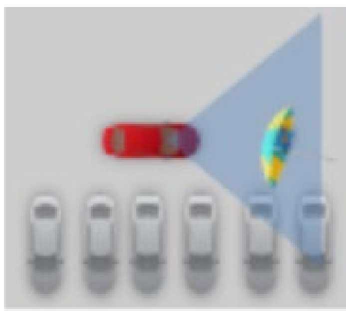
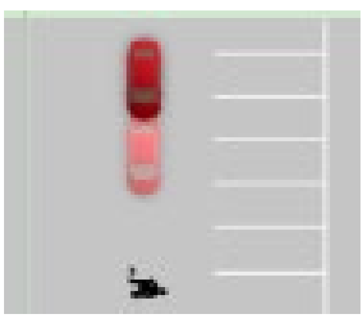
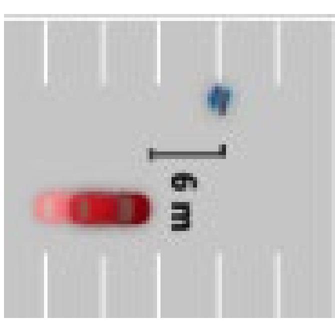
Scenario ID	Scenario Tile	Variation Description
03-06-05		STEER car auto-summons left. Human-driven car (forward-facing) pulls out in the same direction.

03-06-06		STEER car auto-summons left. Human-driven car (forward-facing) pulls out in the opposite direction.
03-07-04		STEER car auto-summons right. Human-driven car (forward-facing) pulls out in the same direction.
03-07-05		STEER car auto-summons right. Human-driven car (forward-facing) pulls out in the opposite direction.

Pedestrian Interactions - Sample Base Scenario

Scenario Description	Scenario Goal
While a STEER car autonomously drives on a straight path, a pedestrian crosses ahead.	The STEER car should detect the obstacle, identify it as a pedestrian, stop at a safe distance, then continue its mission when the path is clear. The STEER car must avoid collision with any obstacle.

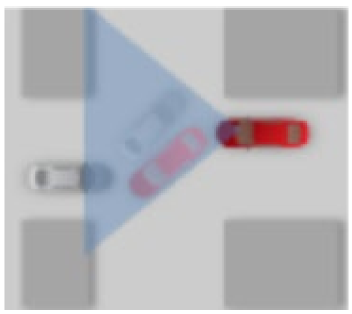
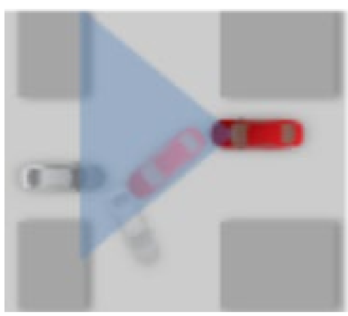
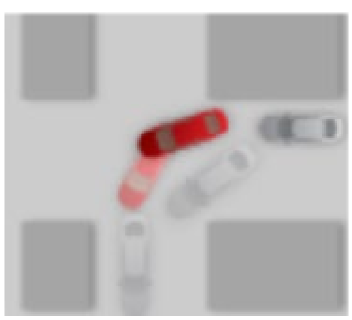
Pedestrian Interactions - Sample Variations:

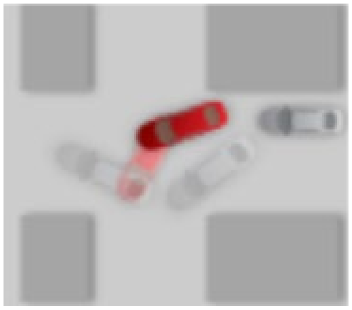
Scenario ID	Scenario Tile	Variation Description
03-05-01		Pedestrian emerges from between parked cars on the STEER car passenger's side. The pedestrian crosses 6m ahead.
02-13-01		Pedestrian holds umbrella as they cross the STEER car's path
02-18-02		STEER car is searching for parking and encounters a kneeling pedestrian in path
03-02-02		Pedestrian crosses STEER car's path 6 meters ahead from STEER's driver's side.

Road User Interactions - Sample Base Scenario

Scenario Description	Scenario Goal
STEER car turns left at a 4-way intersection.	The STEER car should yield for human-driven vehicles. The STEER car must avoid collision with any obstacle.

Road User Interactions - Sample Variations:

Scenario ID	Scenario Tile	Variation Description
02-07-09		Human-driven car ahead of the STEER car turns left after the STEER car has already entered the intersection.
02-08-09		Human-driven car ahead of the STEER car turns right after the STEER car has already entered the intersection.
02-11-08		Human-driven car behind the STEER car attempts to bypass the STEER car, turning left at the intersection.

02-11-09		Human-driven car behind the STEER car attempts to bypass the STEER car, driving straight across at the intersection.

Documenting Test Results

Test results are documented in an internal testing log– an extremely useful database where we can search for and find detailed information for any individual test execution. Data captured in each test execution and recorded in this log includes:

Performance Data

- Scenario success rate
- Description of actual scenario results (PASS and FAIL)
- Total scenario execution time
- Number of disengagements (automatic, manual, safety-critical, non-critical, etc.)

Environment Data

- Test site information (road types, traffic conditions, etc.)
- Weather conditions
- Lighting conditions

Additional Data

- Vehicle software version
- Dashcam recordings
- Session reconstructions

Performance

How We Measure Performance

By exposing our self-driving vehicle to complex scenarios, every mile brings back valuable driving data from which we extract performance metrics. As we update our vehicle software, we track

functional and safety performance, reliability, and resilience through the results of scenario-based tests.

KPI

Every scenario has a pre-defined safety and performance goal that traces back to one or more design requirements and is based on the functional objective of the scenario and the expected response of the vehicle. Scenarios are repeated for a statistically significant number of iterations and are only deemed successful if the driverless vehicle achieves the pre-defined scenario goal ≥90% of the time. On a high-level, our key performance metrics focus on scenario score and success rate.

KPI (unit)	**Output**
Scenario Score (PASS/ FAIL)	Functional performance and capability of the system in a particular instance and environment. **PASS** indicates the system can meet all safety, performance, and quality expectations. **FAIL** indicates the system is not yet capable of meeting all safety, performance, and quality expectations.
Scenario Success Rate (%) (Number of PASS trials) / (Number of total executions) x 100%	Reproducibility of successful results in a *tightly controlled* environment. **A success rate ≥ 90%** indicates the system is meeting our functional safety, performance, and quality expectations *frequently* and *reliably*. **A success rate < 90% but > 60%** indicates the system is meeting our safety, performance, and quality expectations

	at a frequency and reliability rate below our standards; this capability needs revision. **A success rate ≤ 60%** indicates the system is *not* meeting our safety, performance, and quality expectations or is meeting our expectations at an *unacceptable rate; we may have discovered an edge case.*

These performance metrics are powerful in tracing progress over time. When we assess the system's overall performance in a particular skill, we start with these core KPIs. We also refer to other valuable metrics. To evaluate the system's response to safety-critical events, for instance, we might refer to the number of safety-critical disengagements per scenario trial. Safety-critical disengagements include both automatic emergency override responses and manual disengagements performed by safety operators.

PRE-DEPLOYMENT PHASE

The Pre-Deployment Phase was conducted in preparation for testing at the MARC Dorsey station. Before any CAV deployment, several operations needed to be completed satisfactorily. These operations included site assessments and planning, vehicle setup and calibration, site mapping, survey handouts, site inspections, law enforcement and safety stakeholder signoffs, permitting, scenario planning, test design, and infrastructure setup. Site readiness was evaluated by assessing the vehicle behavior on-site, the topology of the site, and the network strength and signal at the

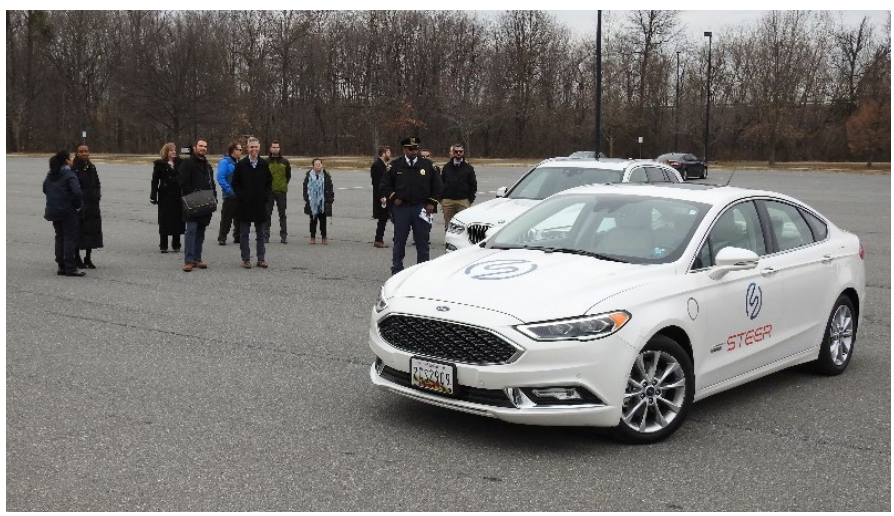


FIGURE 6 Onsite Demonstration for MDOT Officials and Law Enforcement at the MARC Dorsey Station

site. Any issue areas found, either due to the topology or network strength, were excluded from the geofenced region for testing.

The area originally selected on the Dorsey site for Phase 1 closed-course testing was relocated due to external factors. A second area on the same MARC Dorsey Station site, larger in size but with very similar characteristics as the previous area, was rapidly located and assessed (see Figure 7). The site was found to be feasible for use for the Phase 1 testing. One technical issue arose during this task but was successfully handled. Light poles in the testing area affected the signal strength, creating small zones that had spotty coverage. These zones were mapped around and excluded from the final vehicle routes so that the vehicle only traveled in areas with full signal coverage. Testing was able to proceed with that site since the zones were excluded and the car can perform without issue for this study and all the subsequent testing phases.

FIGURE 7 Original Testing Site and Relocated Testing Site at the MARC Dorsey Station

Emergency responder preparation meetings were conducted with local law and fire departments, the MDOT MTA Chief Safety Officer, MARC Commuter Train representatives, MDOT MVA, and MDOT MTA to provide an overview of the project, the project's schedule, objectives, and to demo the automated parking technology in action at the STEER company headquarters. The meetings resulted in thoughtful feedback, operational guidance, and safety-related insights from the respective agencies that enhanced our planning and execution. The Highly Automated Vehicle permit was acquired, and the test site and areas were inspected and secured with fencing and signage on schedule.

PHASE 1 - CLOSED COURSE TESTING

For the Phase 1 testing, a designated area of the MARC Dorsey station's main parking lot (see Figure 8) was sectioned off using fence lines. Appropriate signage for automated vehicle parking was prominently displayed (see Figure 3: Informative Signage). Pre-deployment surveys were handed out by STEER team members and responses were gathered before the start of Phase 1.

During Phase 1, the test team implemented and tested a total of 94 unique scenarios with a total of 980 test runs over four weeks. There were 340 L4 full valets, 201 full summons, 239 point to point driving, and 200 L2+ remote parking scenarios. After the first week of testing, the team internally reviewed test data, operational procedures, and any additional inputs that were received. After the team debrief meeting, testing resumed for three additional weeks. There were no operational challenges in this phase.

FIGURE 8 STEER Vehicle within the Closed Course Boundary

During the site assessment, a small zone within the testing area was found to have insufficient signal strength. This zone was excluded from the planned testing map. However, after completing the planned scenarios for Phase 1, the testing team did experiment by running some tests in the zone we knew to have spotty coverage for deeper development purposes. The vehicle was observed to have delays and the testing operators disengaged to continue the testing relevant to this project. These disengagements were outside of the planned testing map and do not affect the deployment of subsequent phases.

All of Phase 1 closed-course testing was completed between September 2019 to October 2019 at the MARC Dorsey Station.

At the close of Phase 1, STEER Tech compiled a report with the technical process and findings of this phase. The Phase 1 report also outlined any technical or operational issues and the planned schedule and next steps necessary to process to Phase 2 and 3. This report was submitted to and reviewed by MDOT MTA and the Transportation Research Board (TRB).

PHASE 2 - MIXED-USE OFF-PEAK TESTING

After Phase 1 was successfully completed, MDOT MTA and STEER Tech met to review the findings from Phase 1 and lessons learned that could be applied to Phase 2. During this meeting, approval to expand the CAV testing area to include the entirety of the main parking lot at the MARC Dorsey Station for Phase 2 was granted by MDOT MTA (see Figure 9). Pre-deployment operations including site assessment, signal strength testing, scenario planning, and stakeholder signoffs were satisfactorily conducted resulting in approval for STEER Tech to proceed with Phase 2 and 3.

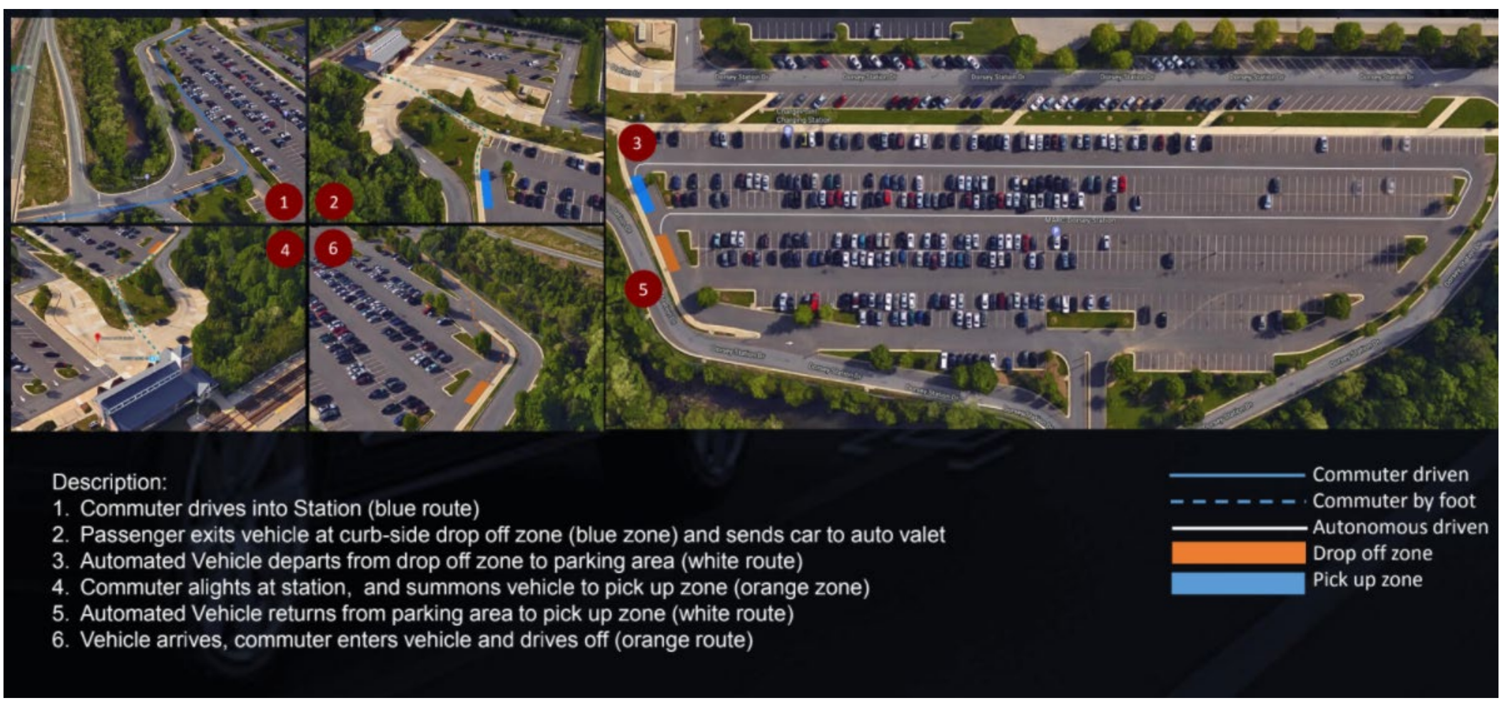


FIGURE 9 Overview of Phase II Testing Map with Designated Drop Off/Pick Up Areas

Phase 2 consisted of mixed-use off-peak testing defined as the testing team testing STEER's CAV in an open lot with no barriers preventing interaction with other drivers or pedestrians. All testing was completed during off-peak commuter hours which were determined by MDOT MTA to be between 10:00 AM and 3:30 PM.

Phase 2 began in January 2020 but was interrupted by the global COVID-19 pandemic. All testing and onsite operations were halted per the governor's directive. Prior to pausing the pilot, the team was able to complete two weeks of mixed-use off-peak testing. Upon approval from TRB, the pilot was extended seven months to allow time to safely return to testing given the circumstances.

Due to decreased ridership and changes in train schedules caused by COVID-19, the planned testing site at the MARC Dorsey station was reassessed and found to no longer be suitable for this pilot. MDOT MTA and STEER Tech worked together to find an alternative site. Several transit stations were evaluated before they were narrowed down to be between the MARC Odenton or MARC Halethorpe stations. MDOT MTA and STEER Tech jointly agreed on the MARC Odenton Station as a better site to complete the pilot (see Figure 10).

Before transitioning to the new site, all the same pre-deployment operations including a site assessment, mapping, meetings with relevant safety officers, and scenario planning were completed. Phase 2 resumed in December 2020 with state and local authorities' approval. All STEER personnel followed COVID-19 protocols including wearing masks, maintaining social distancing practices, and regular disinfecting of the CAV when testing onsite.

Review of IDEA Testing Site for Phase 3 Resumption

The COVID-19 Pandemic has resulted in reduced ridership across Maryland's Commuter Lines. The MARC Dorsey Station particularly has experienced 5-15% occupancy during these times. Ridership is expected to return to pre-COVID levels very slowly. Phase 1 and 2 of the IDEA Testing were successfully conducted at the MARC Dorsey Station. However, decreased ridership due to the COVID-19 pandemic will have a dilutive effect on the remaining testing and therefore premise of the entire testing program.

For Phase 3 of the IDEA testing, STEER recommends moving the autonomous testing to the **MARC Odenton** station. Please see the site assessment and proposed route below. Also included are the site assessment notes from the MARC Halethorpe station.

Pros for the **Odenton Station:**

- The site assessment showed strong GPS connectivity throughout the lot.
- There is a one-way Kiss and Ride area at the front entrance of the train station that makes a great valet drop-off and summon pick-up point.
- The STEER path is away from any high-speed traffic entering the parking lot.
- The STEER path searches for parking in the rear of the parking lot, giving non-STEER drivers priority in the spaces closer to the train station.

Cons *against* the **Halethorpe Station:**

- The site assessment showed a slightly weaker GPS connectivity.
- Long and narrow, 2-lane layout limits the car to navigate and search for parking on a straight path, creating fewer and less creative testing scenarios.
- There are slanted parking spaces that limit the parking areas we can use as slanting requires forward "facing in parking" routines or a complete direction reversal.
- This lot features tight intersections with incoming traffic entering at high-speeds. During peak hours, these intersections could become a congested area making a less optimal testing route
- There is a designated passenger drop-off area, that only fits 2 cars at a time and is in the opposite direction of the valet path.

Note: The commuter density was about the same at both stations at the time of the site assessment. There were approximately 60 cars at each site, mostly condensed at the train station entrances.

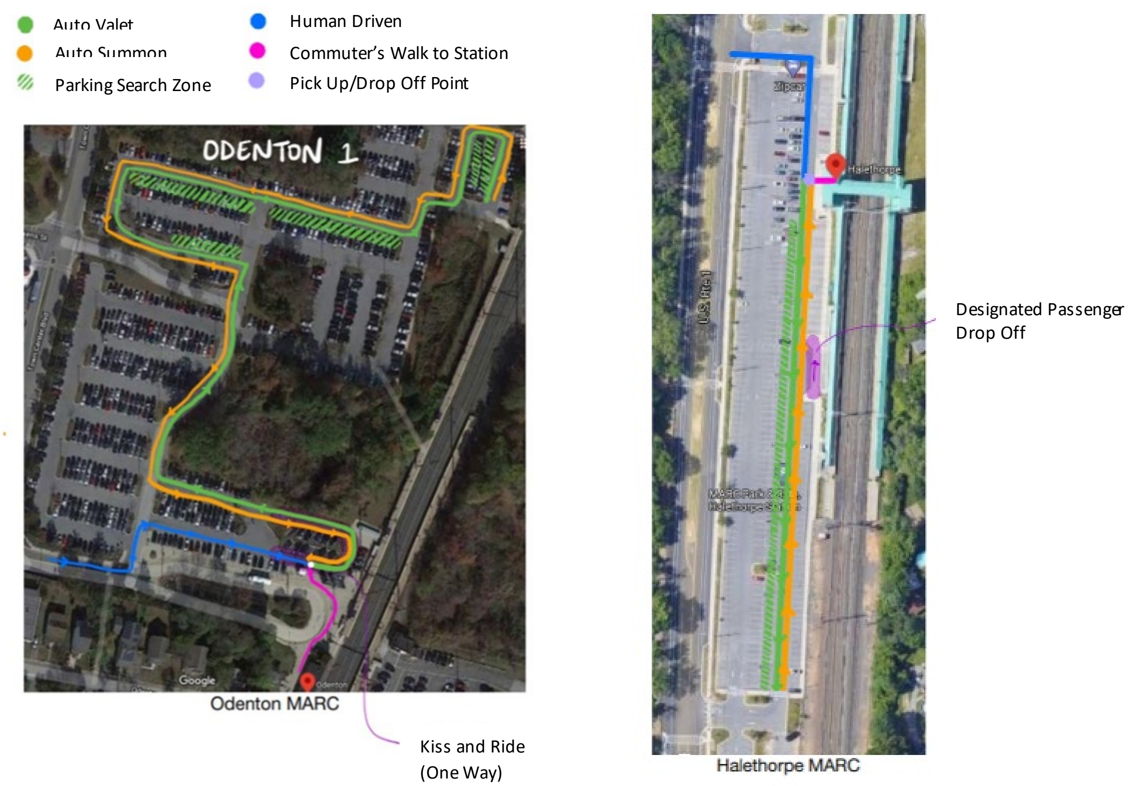


FIGURE 10 Site Justification Report Sumitt4ed Before Resuming Testing

The remaining two weeks of Phase 2 mixed-use off-peak testing were completed at the MARC Odenton station. During all four weeks of Phase 2, the test team implemented and tested a total of 50 unique scenarios with a total of 780 test runs over four weeks. There were 410 L4 full valets, 280 full summons, and 90 point to point driving.

Phase 2 mixed-use off-peak testing was conducted for two weeks at the MARC Dorsey station from the end of January 2020 to the beginning of February 2020. Phase 2 resumed for the remaining two weeks of testing at the MARC Odenton station from December 2020 to January 2021.

PHASE 3 - MIXED-USE PEAK TESTING

Following the completion of Phase 2, MDOT MTA and STEER Tech met virtually to discuss the transition to mixed-use peak testing, and STEER was approved to proceed. The Phase 3 mixed-use peak phase consisted of the team testing STEER's CAV in an open lot with no barriers preventing interaction with other drivers or pedestrians in the same area as Phase 2. All testing during the mixed-use peak phase was completed during peak commuting hours which were determined by MDOT MTA to be between 6:00 AM and 9:30 AM for the morning rush and 3:30 PM to 7:30 PM for the evening rush.

Phase 3 involved testing one autonomous vehicle for three weeks and two autonomous vehicles for one week in the mixed-use area. During the week of two autonomous vehicles testing, one day was spent testing scenarios where the vehicles drove the same route that they individually mapped (instead of using the same map).

The test team implemented and tested a total of 66 unique scenarios with a total of 1,015 test runs over the four weeks of Phase 3 testing. There were 562 L4 full valets, 329 full summons, and 124 point-to-point driving scenarios executed during this time.

Phase 3 was completed entirely at the MARC Odenton station from January 2021 through March 2021. The end of Phase 3 completed the CAV testing portion of the pilot.

Throughout the three testing phases, 165 hours of autonomous vehicle testing were completed which consisted of 210 unique scenarios and a total of 2,775 test runs.

Project Phase (Environment - Location)	Unique Scenarios Tested	Total Test Runs	Full Valet Count	Full Summon Count	Total Disengagements	Scenario Runtime
1 (Isolated - Dorsey)	94	980	340	201	14	56:24:00
2 (Off Peak - Dorsey/Odenton)	50	780	410	280	3	49:31:00
3 (Peak - Odenton)	66	1015	562	329	93	59:04:00
Grand Total	**210**	**2775**	**1312**	**810**	**110**	**164:59:00**

TABLE 1 Overview of Testing Stats for All Three Phases

COVID-19 COMPLICATIONS

The *Connected and Automated Parking Feasibility Pilot* was underway with the expectation to complete the CAV testing portion of the pilot by April 2020 when the global COVID-19 pandemic halted all onsite operations. Due to COVID-19, the testing phases had to be temporarily paused from February 2020 through December 2020 which shifted the entire pilot schedule (see Table 2). When testing was cleared to resume, the significantly decreased ridership at the original testing site, the MARC Dorsey station, caused MDOT MTA and STEER to relocate testing to a slightly more populated site, the MARC Odenton station.

Updated Testing Schedule with Disruption Due to COVID		
Task Name	**Start**	**Finish**
Pre-Deployment Field Operations	Mon 8/26/19	Fri 9/13/19
Parking Lot Mapping - Both sites	Mon 8/26/19	Fri 8/30/19
Pre-Deployment Survey	Tue 9/3/19	Tue 9/10/19
Deployment Preparation/MDOT MTA Site Inspection	Mon 9/9/19	Tue 9/10/19
Obtain HAV Testing Permit	Thu 9/12/19	Thu 9/12/19
MDOT MTA Site Inspection	Wed 9/11/19	Fri 9/13/19
Automated Parking Deployment - Phase 1 (Closed Course)	Mon 9/16/19	Fri 10/18/19
First Week of Phase 1 Testing	Mon 9/16/19	Fri 9/20/19
Team Debrief on First Week of Phase 1 Testing	Fri 9/20/19	Fri 9/20/19
Phase 1 Testing Resumes	Mon 9/23/19	Fri 10/11/19

Survey 1	Mon 9/30/19	Fri 10/4/19
Bi-Weekly Check-In	Fri 10/4/19	Fri 10/4/19
Phase 1 Testing Concludes	Fri 10/11/19	Fri 10/11/19
Phase 1 Report Due	Fri 10/18/19	Fri 10/18/19
Automated Parking Deployment - Phase 2 (Off-Peak)	Mon 12/16/19	Fri 1/8/21
First Quarterly Report Due	Tue 11/5/19	Tue 11/5/19
Pre-Deployment Operations	Mon 12/16/19	Wed 12/18/19
Install Signage, Site Inspection, Preparation		
First Week of Phase 2 Testing	Mon 1/20/20	Fri 1/24/20
Team Debrief of First Week of I2 Testing	Fri 1/24/20	Fri 1/24/20
Phase 2 Testing Resumes	Mon 1/27/20	Tue 2/4/20
Bi-Weekly Check-In	Fri 1/31/20	Fri 1/31/20
Operations Paused Due to COVID-19 Pandemic		
Phase 2 Testing Resumes	Tue 12/8/20	Thu 12/17/20
Survey 2	Mon 12/14/20	Fri 12/18/20
Bi-Weekly Check-In	Tue 12/22/20	Tue 12/22/20
Phase 2 Testing Concludes	Fri 1/8/21	Fri 1/8/21
Automated Parking Deployment - Phase 3 (Peak)	Wed 2/3/21	Mon 4/5/21
Cleared to Proceed to Phase 3 Testing	Fri 1/8/21	Fri 1/8/21
First Week of Phase 3 Testing	Wed 2/3/21	Tue 2/9/21
Team Debrief of First Week of I3 Testing	Tue 2/9/21	Tue 2/9/21
Phase 3 Testing Resumes	Wed 2/10/21	Tue 3/9/21
Bi-Weekly Check-In	Tue 2/23/21	Tue 2/23/21
Phase 3 Testing Concludes	Tue 3/9/21	Tue 3/9/21
Survey 3	Mon 4/5/21	Mon 4/5/21

TABLE 2 Updated Testing Schedule with Interruption Due to COVID-19

Even with the relocation of the testing site, the sharp decrease in ridership due to COVID-19 had a profound impact on the number of survey responses gathered from commuters. With a fraction of commuters utilizing the stations and with restricted survey data collection methods, there was an unexpected low response rate to the three final surveys.

PLANS FOR IMPLEMENTATION

Commuter Rail ridership is estimated to slowly return to regular levels within the next 1-2 years. This slow return will allow MDOT MTA to analyze ridership increase patterns and parking lot usage to determine further uses of AVP to either attract rider return or ease strained lots. In preparation for eventual return, additional lots could potentially be mapped for future AVP or CAV uses.

STEER Tech and MDOT MTA are developing a strategic mapping plan that entails mapping commuter transit stations across the state as ridership starts to rise again post-COVID. By mapping a network of transit stations, Maryland becomes increasingly prepared for the adoption of AVP technology. Adding more stations to the CAV mapped network enables MDOT and transit commuters to further realize the benefits of AVP including increased rider safety and convenience, and increased revenue for the transit agency. As part of the mapping plan, there is the potential to include designated AVP-only zones with compact parking spaces at the newly mapped stations. Mapping specific zones for CAVs to autonomously park maximizes the space-saving benefits at each station due to the close distances that the vehicles can park. The mapping plan is still in development and will be approved by MDOT before STEER begins mapping.

CONCLUSIONS

Although there were unprecedented disruptions due to the COVID-19 pandemic, the *Connected and Automated Parking Feasibility Pilot* yielded significant results that can be utilized by transit agencies to further improve and innovate commuter stations.

When AVP technology is implemented, parking lot capacity can be increased 20% depending on the layout of the parking lot. During the testing phases, the STEER CAVs were able to park within 10 centimeters of the adjacent vehicles. And with no need to enter or exit the autonomously parked vehicles, parking space sizes can be decreased, allowing for more spaces in

the existing lots. To maximize parking efficiency, STEER Tech recommends AVP be deployed in lots with straight (not slanted) parking spots.

For CAVs to safely operate, the vehicles must have a reliable and secure cellular connection. For transit stations that have parking garages, additional infrastructure may be needed to boost the cellular signal required for the CAVs. For surface lots, large surrounding buildings or trees may affect the cellular signal strength of the CAVs. Site assessments done by qualified STEER technicians can help determine any low signal strength areas and exclude those areas from the custom CAV maps. Signal strength issues can be identified and resolved by completing a pre-deployment site assessment. STEER Tech completed pre-deployment site assessments for each testing phase and was able to identify and mitigate issues such as low signal strength areas and parking design to maximize efficiency.

SURVEY FINDINGS

To understand the commuter opinion of CAVs, gauge how CAVs would potentially impact ridership, and receive direct feedback during the testing phase, four surveys were distributed to commuters. The first survey was distributed during the Pre-Deployment phase and was handed out in-person at the MARC Dorsey station and two additional stations within close proximity, the MARC Halethorpe station and MARC BWI station, in order to increase the number of survey takers. The remaining surveys were electronically shared with the batch of survey takers who had responded to the first Pre-Deployment survey. One of the three remaining surveys was shared during each of the testing phases. Decreased ridership due to COVID-19 and inconsistent commuter responses resulted in varying sample sizes for each survey. The decreased number of survey respondents and

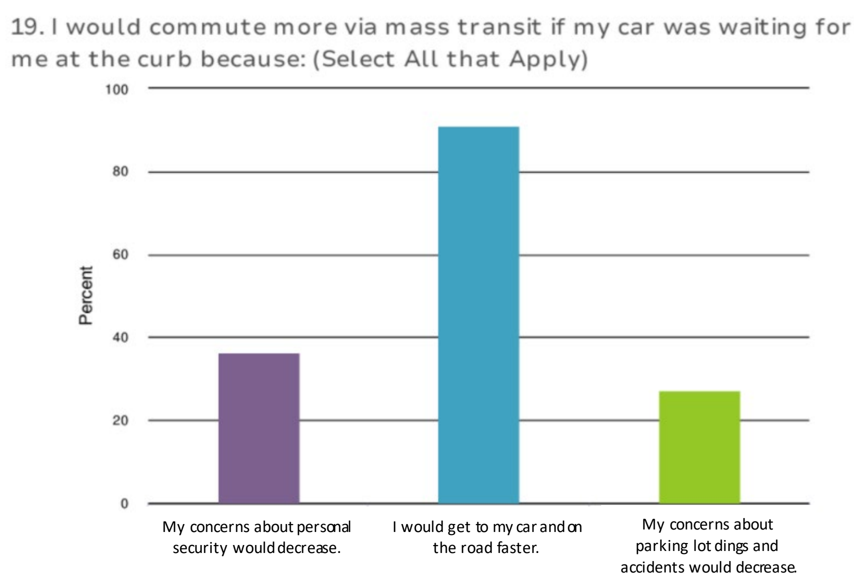


FIGURE 11 Example Results from One of the Survey Questions

interest in the pilot directly correlates with the decreased ridership and mass transit use due to COVID-19 complications.

Survey Name	Pre-Deployment Survey	Phase 1 Survey	Phase 2 Survey	Phase 3 Survey
Number of Respondents	105	36	4	19

TABLE 3 Survey Respondents Per Survey

Considering the relatively low response rate, commuters stated that seeing STEER's automated vehicle made them feel more comfortable with AVs with 45% of respondents saying that the IDEA pilot and having the STEER CAV on-site increased their interest in the autonomous vehicle industry. Out of 141 respondents, 43% stated that they would feel comfortable using CAV tech in parking lots and 60% of respondents said they would use technology like STEER at transit stations.

Knowing that commuters are interested in and willing to use CAV technology, transit agencies could improve the commuter experience by implementing automated valet parking.

- 25% of respondents stated how long it takes them to park and walk to the station as their biggest frustration with public transit (n = 36). STEER eliminates this pain point completely by dropping riders off at the entrance and autonomously parking for them.
- 25% of respondents said they deliberately go to underutilized stations instead of the stations closest to them so they can have a better parking spot (n = 59). Implementing AVP transforms stations with overcrowded parking lots into accessible and desirable stations and eliminates the need for commuters to travel further to reach a commuter station.
- 74% of respondents stated that they would prefer if parking lots had designated traffic patterns (n = 23). STEER can help enforce traffic policies like this via their automated driving technology and customized mapping for each transit station.

Along with improving the commuter experience, transit agencies could improve rider safety with AVP which, in turn, could increase ridership.

- 42% of riders said they never feel safe or only feel safe if they park their car close when in a public parking lot (n = 124) and 74% of riders saying that technology that picked them

up curbside, such as STEER, would make them feel safer when commuting. With STEER, riders can summon their car back to them when they arrive at the station and can wait in the well-lit, populated areas for their car. Riders would no longer need to walk through dark or dimly lit parking lots alone, increasing the personal safety of commuters.

- 74% of respondents said they would commute more via mass transit if their car picked them up curbside because their concerns about personal security and potential accidents would decrease (n =19).
- 3% of riders said they would commute via public transit more if they felt safer (n =160).

In general, transit agencies could increase ridership by implementing AVP.

- On average, 23% of riders said they would commute via public transit more if they didn't have to deal with the parking lot or parking at the stations (n = 160).
- Considering low sample sizes, 52% of respondents said that they would commute via public transit more if the time it took them to park was consistent with 25% of respondents saying they would commute via public transit more if their car was waiting for them at the curb when they got back to the stations

Survey Question	Pre-Deployment Survey - 105	Iteration 1 Survey - 36	Iteration 2 Survey- 4	Iteration 3 Survey - 19	Sample Size	Total # of Respondents	% for Answer
I feel comfortable driving in a parking lot where autonomous vehicles also drive and park.	Yes 67 No 27				113	67	59.29%
The statement chosen below best aligns with how safe I feel when using public transportation/in parking lots or garages:	I never feel safe if I'm alone 6 I feel safe during the day and at night if my car is parked close 37			I never feel safe if I'm alone 3 I feel safe during the day and at night if my car is parked close 6	124	52	41.94%
If my car was waiting for me right when I got out of the station, I would be less worried about getting in an accident.				True 8	19	8	42.11%
If my car was waiting for me right when I got out of the station, I would feel an increase in my personal safety and security.			True 3	True 14	23	17	73.91%
I feel safe using a car with autonomous technology or I feel safe when cars around me are using autonomous technology: (Check all that apply)	In a parking lot 42	In a parking lot 18			141	60	42.55%
I would commute more via MARC if: (Check all that apply)	The parking lot wasn't so full/busy 10 I didn't have to park my car at all 12	The parking lot wasn't so full/busy 3 I didn't have to park my car at all 3		The parking lot wasn't so full/busy 4 I didn't have to park my car at all 4	160	36	22.50%
I would commute more via MARC if: (Check all that apply)	I felt safer when I commuted 2	I felt safer when I commuted 2		I felt safer when I commuted 1	160	5	3.13%
I would use an autonomous parking technology at: (Check all that apply)	Commuter Train Stations 57	Commuter Train Stations 27			141	84	59.57%
On an average day, I spend this long searching for parking and walking to my destination. (Total time spent over the course of the day.)		5 - 10 Minutes 12 10 - 15 Minutes 4	10 - 15 Minutes 1 15 - 20 Minutes 1	5 - 10 Minutes 7 10 - 15 Minutes 2	59	27	45.76%
My biggest frustration with commuting via MARC is:		How long it takes me to park and walk to the station 9			36	9	25.00%
I would commute more via mass transit if my car was waiting for me at the curb because: (Check all that apply)				My concerns about personal security would decrease. 8 My concerns about parking lot dings and accidents would decrease. 6	19	14	73.68%
I deliberately went to a station because I knew it is underutilized and I would always get a parking spot over the station that is located closest to me.		True 4	True 1	True. 10	59	15	25.42%
I would prefer it if all cars - whether driven or self-driving - had to follow a designated traffic pattern in the station parking lots.			Agree 1 Strongly Agree 1	Agree 5 Strongly Agree 10	23	17	73.91%
If the amount of time it takes for me to park at the station was consistent, I would commute via mass transit more frequently.			True 1	True 11	23	12	52.17%
If my car was waiting for me at the curb when I got out of the station, I would commute via mass transit more frequently.			True 1		4	1	25.00%
Seeing the self-driving car has increased my interest in the autonomous vehicles.		True 16			36	16	44.44%

TABLE 4 Survey Findings Summary

The findings from both the implementation of CAV technology at the transit stations and from the surveys conducted during the implementation can inform transit agencies on how to best integrate the proven beneficial CAV technology into their sites.

Further testing is needed to understand the full extent to which connected and automated vehicles (CAVs) can improve and affect mass transit ridership. However, even with the unique circumstances imposed by the COVID-19 pandemic, the *Connected and Automated Parking Feasibility Pilot* proved that the implementation of CAV technology is feasible now for transit agencies and will reap a myriad of benefits. Benefits include, but are not limited to, increased ridership due to commuter's increased personal safety and an overall improved experience for commuters. Additionally, transit agencies would be able to expand the parking capacity of existing lots without adding any infrastructure or costs. These benefits were tested and proven at underutilized transit stations which speaks to the potential improvements connected and automated vehicles could provide at near-capacity or overutilized sites.

REFERENCES

1. Cookson, Graham. "The Impact of Parking Pain in the US, UK and Germany." *Inrix*, July 12, 2017. https://inrix.com/press-releases/parking-pain-us/.