TREASURE ISLAND
MOBILITY MANAGEMENT AGENCY

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Memorandum

AGENDA ITEM 5

DATE: June 7, 2024

TO: Treasure Island Mobility Management Agency Committee

FROM: Suany Chough, Assistant Deputy Director for Planning

SUBJECT: 06/11/24 Committee Meeting: Accept the Treasure Island Autonomous Vehicle Shuttle Pilot Project Final Report

RECOMMENDATION ☐ Information ☒ Action

Accept the Treasure Island Autonomous Vehicle (AV) Shuttle Pilot Project Final Report.

☐ Fund Allocation
☐ Fund Programming
☐ Policy/Legislation
☒ Plan/Study
☐ Capital Project Oversight/Delivery
☐ Budget/Finance
☐ Contract/Agreement
☐ Other: ____________

SUMMARY

The Treasure Island AV Shuttle Pilot Project (Pilot), called the "Loop" was a demonstration of an on-island shuttle serving Treasure Island. The Pilot was planned to operate for nine months, through Spring 2024, and concluded in early (January 2024) due to changing roadway configurations on the Island. The duration of service provided fulfilled the requirements of the federal Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant and was the basis for an evaluation of the Pilot. The enclosed Treasure Island AV Shuttle Pilot Project Final Report includes a detailed discussion on the Pilot's preparation, deployment, data analysis and findings, and community engagement and partnership efforts. While the Pilot presented a number of technical challenges in operation, the shuttle was consistently used for on-island trips and perceptions around AVs generally remained neutral or slightly improved after interacting with the Loop.

BACKGROUND

In 2016, we collaborated with the San Francisco Municipal Transportation Agency (SFMTA), the San Francisco County Transportation Authority (Transportation

Authority) and other local partners to win an ATCMTD grant from the US Department of Transportation (USDOT), also known as the "Smart City" grant. Administered by the Federal Highway Administration (FHWA), the grant program sought showcase technology solutions aimed at reducing traffic congestion and creating safer and more efficient transportation systems. TIMMA partnered with SFMTA to propose testing and deployment of shared AVs on Treasure Island. The goal was to demonstrate clean, shared, and accessible first/last-mile AV shuttle transportation on Treasure Island, and to assess technical performance and public perceptions of the innovative service. As the lead transportation agency overseeing Treasure Island's transportation program, we led the implementation of the AV shuttle pilot service, known as the Loop. We were also awarded a federal Innovative Deployments to Enhance Arterials Shared Automated Vehicles Program grant from the Metropolitan Transportation Commission, which helped fund additional service and community engagement and partnership efforts.

The TIMMA Board approved the award of a contract to Beep, Inc. (Beep) to operate the AV shuttle in October 2022. The project was among the first pilots in California to demonstrate shared AV shuttle service on public roads.

The Loop pilot was funded largely with regional and federal grants matched with a Prop K sales tax appropriation, to test AVs on a limited basis to better understand the technology and its capabilities, and to explore related workforce development, economic development, educational, and other opportunities to promote learnings and local participation in this emerging industry.

DISCUSSION

Pilot Overview. The Loop used multi-passenger, ADA-compliant, fully electric shuttles and operated on a fixed route on Treasure Island with pre-designated stops on Treasure Island (see Attachment 1). The Loop was scheduled to operate every 30 minutes from 9am to 6pm daily, and a safety attendant was always on board when a vehicle was in operation. The enclosed final report describes the permitting, training, and testing procedures required before passenger service could begin. All permits were secured by June 2023, and the service launched on August 16, 2023.

Due to changing roadway configurations on Treasure Island, TIMMA suspended the Loop service on December 10. The study team worked with Beep to explore ways to resume the service, but the time and cost to re-map and re-permit the shuttle route was prohibitive. In early January 2024, TIMMA announced that the Loop demonstration pilot would be ending early, and turned to the project's community workshop and evaluation activities.

The Pilot included ongoing community engagement and partnership efforts. Prior to launching the Pilot, the Loop team held engagement events for the community to see the vehicle and ask the project team about the service and technology. We also held an ADA focused event to seek feedback on the accessibility of the vehicle and service. Community partnership events were held with the Willie Brown Elementary STEM program and local labor to increase visibility into job opportunities and pathways in the AV industry.

Evaluation. The Pilot had four goals, which were used to guide the overall evaluation, listed below. We worked extensively with Beep to ensure data availability to support the evaluation around these goal areas.

- Without risking the safety of the public, understand the safety features and capabilities of an AV shuttle
- Understand if/how AV shuttle technology can support mobility on Treasure Island
- Understand organizational and infrastructure needs to operate an AV shuttle
- Gather insights from the public and data from the AV technology during the pilot and share lessons learned

Pilot Findings. The Loop operated through mid-December 2023. Overall, the Pilot showed in many ways that demand exists for first and last mile solutions. Throughout the project, the local community was actively engaged and interested in learning more about a new way to travel around the Island.

While popular with riders, the service was marked by operational challenges and unreliability from the beginning. The project contract included two vehicles operating between 9am-6pm, daily and access to a backup vehicle to cover instances where a vehicle went out of service. During operations, TIMMA found the vehicles to be unreliable, with each vehicle being taken out of service for extended periods due to hardware and software issues. As a result, two shuttles were not in consistent operation, impacting service reliability and overall operational performance. By the third month, the Loop operated with two shuttles and achieved the target service.

Through survey efforts and ridership data, the study team found that the shuttle had consistent ridership and perceptions around autonomous vehicles generally remained neutral or improved after interacting with the Loop vehicles.

The enclosed Treasure Island Autonomous Vehicle Shuttle Pilot Evaluation Report includes a detailed discussion on the permitting process, data requirements, data analysis and findings, community engagement and partnership efforts, and a business case to assess the operational considerations between operating an autonomous shuttle and public transportation.

FINANCIAL IMPACT

Acceptance of this final report does not have a financial impact.

TIMMA completed the federally funded grant scope of work and pilot deployment. Due to the early termination of the pilot, remaining funds from the MTC's federal IDEA SAV grant will be returned to MTC.

SUPPLEMENTAL MATERIALS

- Attachment 1 – The Loop Route Map
- Attachment 2 – Treasure Island Autonomous Vehicle Shuttle Pilot Project Final Report
- Attachment 3 – Resolution

TIMMA
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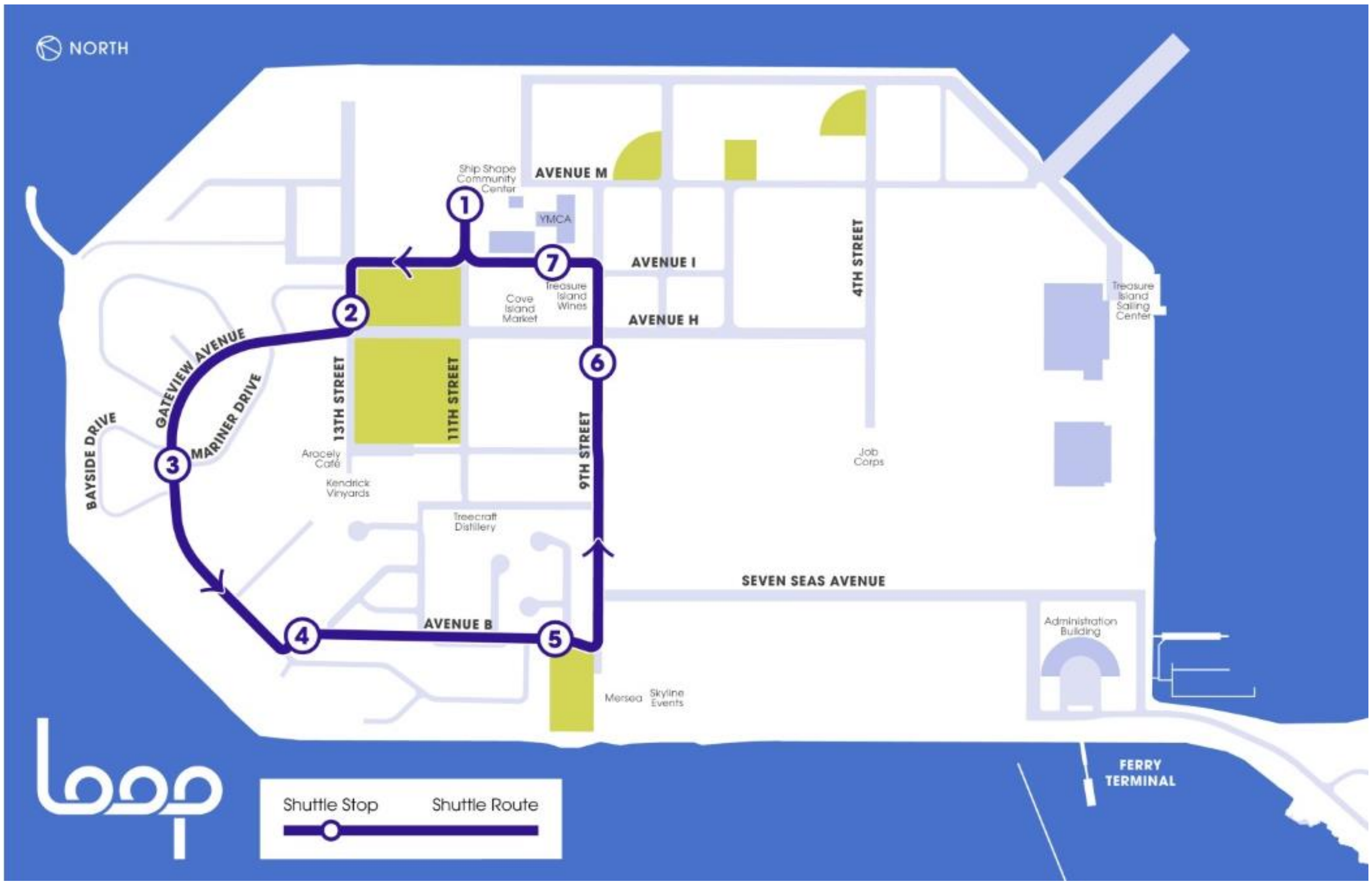
Attachment 1

Project Map – Pilot Route and Stops



Attachment 2

The Loop
Final Evaluation Report

TREASURE ISLAND MOBILITY MANAGEMENT AGENCY

Draft Report: June 2024

Acknowledgments

The Loop Pilot Project was one of the first demonstrations of shared AV services providing passenger service on public roads in California. We launched the Loop service in August 2023 and are grateful to the community and our partners for their support and engagement in the program.

The project was funded through the US Department of Transportation (USDOT), also known as the "Smart City" grant. Administered by the Federal Highway Administration (FHWA), a Metropolitan Transportation Commission (MTC) Innovative Deployments to Enhance Arterials Shared Automated Vehicles (IDEA SAV) grant, and local Prop K Transportation Sales Tax funds.

We want to extend special thanks to our operating partner Beep, funding partners Federal Highway Administration, MTC, Treasure Island Development Authority, and the Transportation Authority, regulatory agencies National Highway Traffic Safety Administration, and California Department of Motor Vehicles, as well as to our community and local partners at Treasure Island Development Authority, One Treasure Island, and the San Francisco Municipal Transportation Agency for their support and collaboration.

This report was supported by the San Francisco County Transportation Authority through a grant of Prop K transportation sales tax funds

San Francisco County Transportation Authority

PROJECT TEAM

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Executive Summary

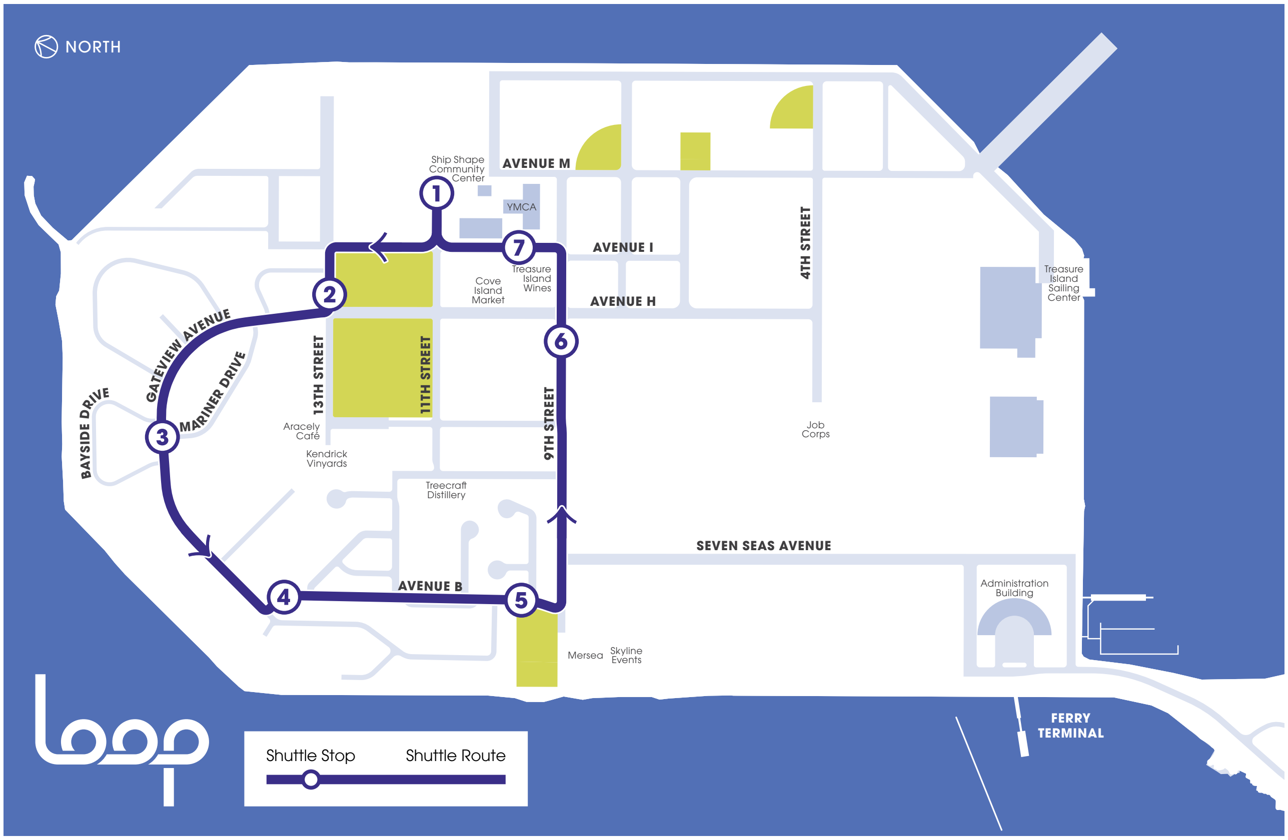
Introduction

In August 2023, the Treasure Island Mobility Management Agency (TIMMA), in collaboration with the San Francisco Municipal Transportation Agency (SFMTA), and the Treasure Island Development Authority (TIDA), launched operations of the Treasure Island Shared Autonomous Vehicle (AV) Pilot Project. The project, known as "the Loop", was among the first pilots in California to demonstrate shared AV shuttle service on public roads. It provided a free passenger service open to the public on Treasure Island for four months. The Loop operated daily from 9 a.m. and 6 p.m. along a seven-stop, one-and-a-half-mile route, at 30-minute frequencies, shown in Figure 0-1. The pilot was funded by grants from the Federal Highway Administration, Metropolitan Transportation Commission, and San Francisco County Transportation Authority.

Treasure Island, a neighborhood in San Francisco, sits in the San Francisco Bay apart from mainland San Francisco. Treasure Island is being transformed into a mixed-use neighborhood with 8,000 new homes, 27% of them affordable, with significant infrastructure improvements and a new street grid. It is the site of active ongoing construction. Treasure Island is connected to the mainland by the Bay Bridge, which provides automobile access and bus service operated by the SFMTA, and by a ferry that operates from a terminal at the south end of the island.

The purpose of the Loop shuttle was to demonstrate a first-last mile circulator application of a shared, autonomous service, and to gauge its technical performance as well as public opinion. The Loop was originally intended to provide local circulation and a connection to the ferry terminal to support access to downtown San Francisco. However, due to challenges providing dedicated pullout spaces for the shuttle along Seven Seas Avenue, which would have connected the Loop to the ferry terminal, the ferry connection was removed. The Loop shuttle served residential neighborhoods, local businesses, and public facilities in the north end of Treasure Island.

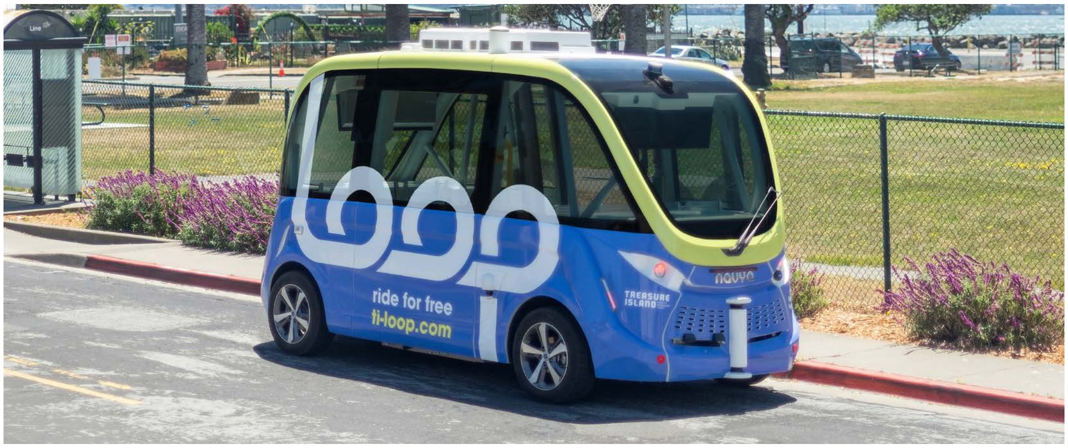
Figure 0-1. The Loop Route



The Loop used three fully electric shuttles capable of Level 3 vehicle autonomy which can operate on its own under certain conditions, but must have a safety driver present and ready to take over. The shuttles, provided by Beep and manufacturer Gaussin Macnica Mobility (GMM, formerly Navya), operate on a fixed, pre-mapped route. The shuttles, shown in Figure 0-2, could accommodate up to 10 passengers, or eight passengers and one wheelchair passenger. Beep, Inc. (Beep) operated the shuttle service and provided an on-board attendant/safety driver to navigate stop-controlled intersections, assist passengers, and deploy manual ramps to support rider accessibility.

Prior to launching service, Beep obtained the necessary federal and state permits and insurance, and the shuttles were tested for a 30-day period. The team held workshops with first responders and SFMTA bus operators to ensure both services could operate along the route simultaneously. Working with One Treasure Island, TIMMA also conducted outreach to the Treasure Island community to publicize the service, and met with representatives from labor groups to engage them on pilot design. TIMMA also set up a survey for riders and non-riders that remained open throughout the duration of the pilot.

Figure 0-2. The Loop AV Shuttle

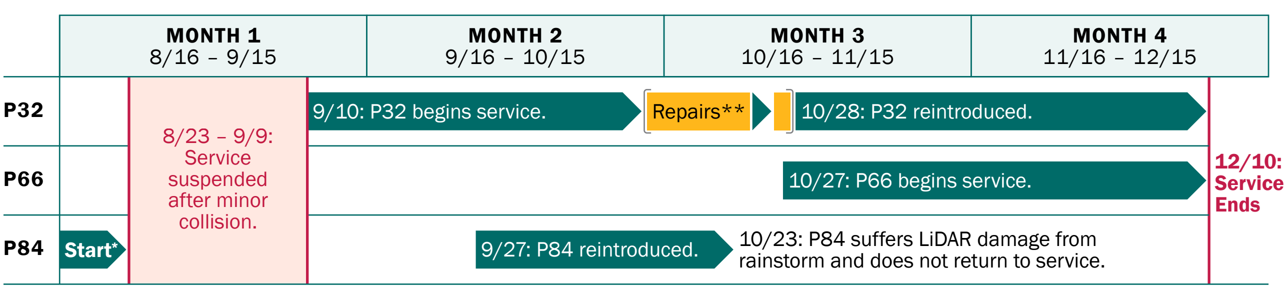


Pilot Service Overview

The Loop service operated on Treasure Island from mid August 2023 to mid December 2023. While popular with riders, the service was marked by operational challenges and unreliability from the beginning. Originally planned as a two-shuttle operation with support from a spare vehicle, the service ran with a single shuttle following launch of the service in late August due to mechanical vehicle issues, and was then suspended for nearly three weeks, due to a non-injury collision. Service resumed with a single shuttle in early September and in late September, the Loop operated with two shuttles and achieved the target service in late September. Thereafter, following a few disruptions in October, the Loop operated mostly as planned through November and early December. Due to changing roadway configurations on the Island, the Loop service was paused on December 10. TIMMA worked with Beep to explore ways to resume the service, but the time and cost to re-map the shuttle route was prohibitive.

In early January 2024, TIMMA announced that the Loop demonstration pilot would be ending early, and work turned to evaluating the four-month initial phase of the pilot.

Figure 0-3. Loop Operations Summary



* 8/16: Service begins with P84 only. P32 does not begin service due to curb strike. P66 remains in testing due to LiDAR issues.

** 10/14 – 10/28: P32 undergoes repairs, is briefly returned to service, and undergoes further repairs until being reintroduced to service once again

Evaluation

The evaluation used four months of operational data for following reporting timeframes:

- **Month 1:** August 16, 2023 – September 15, 2023
- **Month 2:** September 16, 2023 – October 15, 2023
- **Month 3:** October 16, 2023 – November 15, 2023
- **Month 4:** November 16, 2023 – December 10, 2023

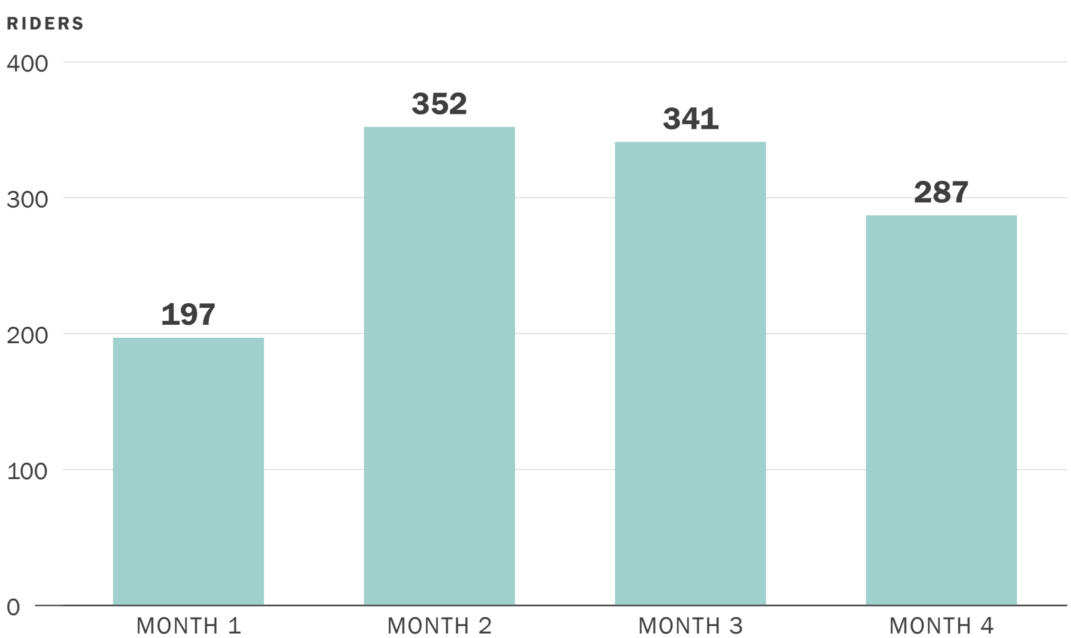
Data exports from on-board vehicle equipment logs provided vehicle movement and location data. All other data was collected manually by on-board attendants. In addition, TIMMA solicited community feedback through rider and non-rider surveys conducted online. Utilizing this data the following sections present highlights from evaluation findings in the areas of mobility, operations, safety, and outreach.

MOBILITY

Ridership

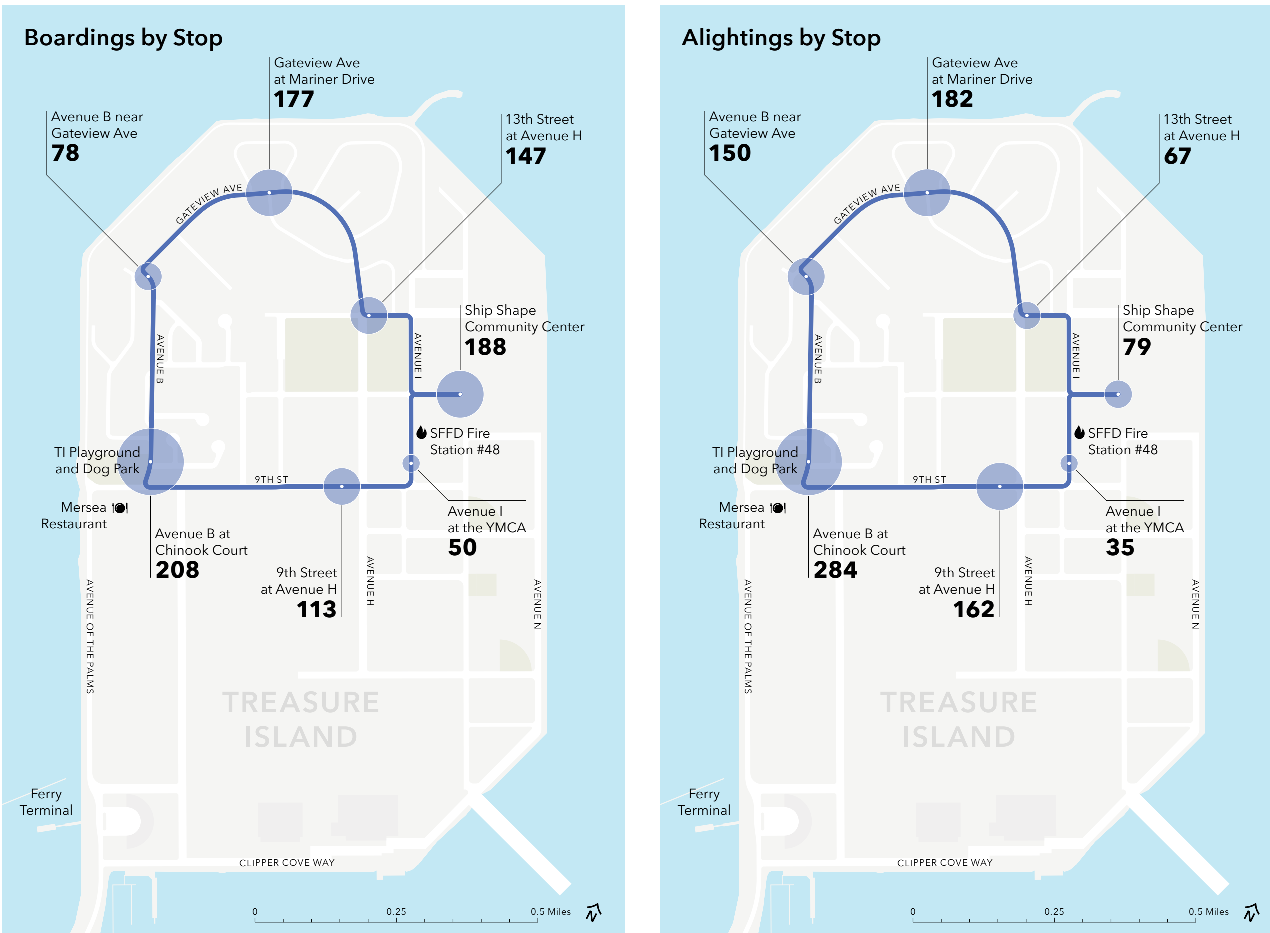
A total of 1,177 passengers boarded the Loop. Ridership peaked in Month 2 at about 350 riders and remained almost as high in Month 3 (see Figure 0-4). Month 1 and Month 4 had lower ridership due primarily to service interruptions. Average daily ridership was highest from 2 p.m. to 6 p.m. when 61% of boardings occurred.

Figure 0-4. Monthly Ridership



As shown in Figure 0-5, Avenue B at Chinook Court was the most boarded and most alighted stop on the route. The Ship Shape Community Center hosts a local food pantry on Tuesdays between 2 p.m. and 5 p.m. Data for this stop shows that 68% of all riders who boarded the Loop at the Ship Shape Community Center did so on Tuesdays between the 2 p.m. and 5 p.m. hours.

Figure 0-5. Mapping of Stop Boarding and Alightings Across All Months



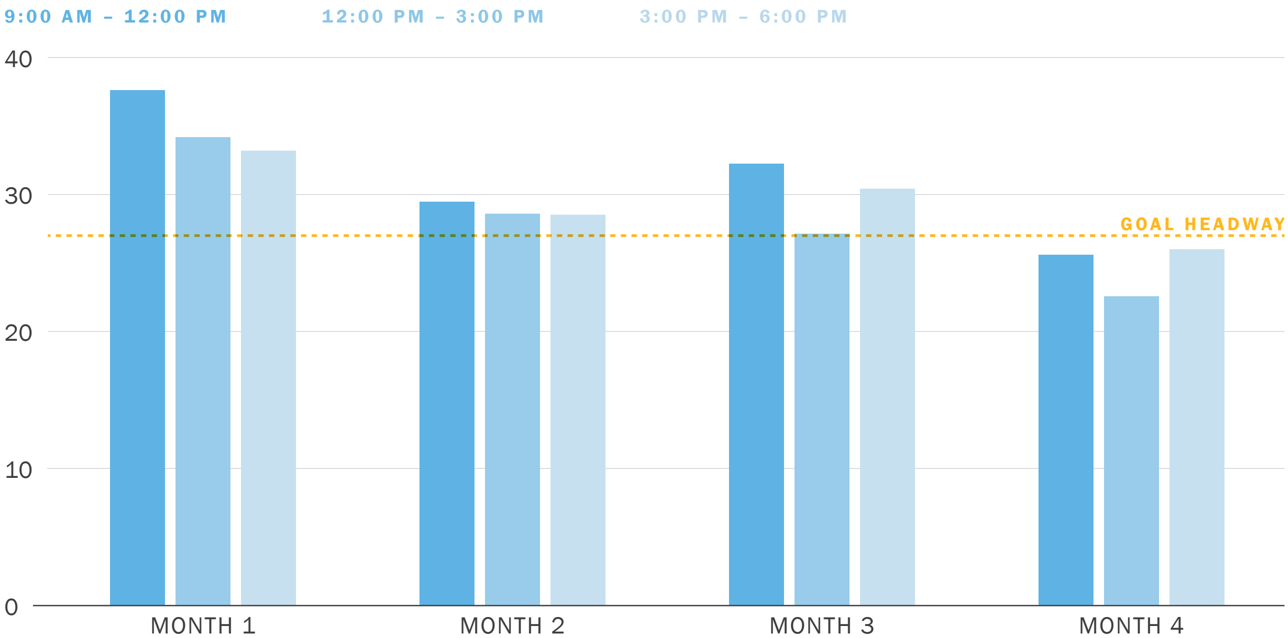
Note: the Ridership Report by Stop was finalized in September 2023. Please note that ridership data prior to September has been omitted.

OPERATIONS

Headways

The operational goal for the project was to achieve an average of 27-minute headways. Consistently meeting the goal of 27-minute headways did not occur until Month 4, when two shuttles were consistently in service. Across all months, headways were often shorter during midday operations. This is likely due to the one-hour time block (12 p.m. – 1 p.m.) when, if possible, two shuttles operated simultaneously.

Figure 0-6. Average Headways in Minutes by Time of Day



Service Uptime

Service uptime, measured by the percentage of scheduled runs that were completed, fell short of the average monthly service uptime goal of 95% in three of the four months (see Table 0-1). The Loop service uptime varied widely from 30% to 102% with an average of 78% of planned runs delivered over the duration of the pilot.

Table 0-1. Monthly Service Uptime

	TOTAL RUNS COMPLETED	EXPECTED RUNS COMPLETED	% RUNS COMPLETED
Month 1	206	682	30%
Month 2	609	645	94%
Month 3	598	682	88%
Month 4	560	528	106%
Total	**1,973**	**2,537**	**78%**

SAFETY

Disengagements

Disengagements are instances where the AV disengages autonomous mode and requests manual operation from the shuttle on-board operator. There were a total of 358 shuttle disengagements during the pilot. The three most common causes were:

- "Other Road Users" occurred when a vehicle was detected as an obstacle due to close proximity to the shuttle's path.
- "Obstacle Detection" occurred when an object was detected within the path and prevented autonomous operation.
- "Signal Loss" occurred when the shuttle lost signal to 5G (cellular communications protocol), global navigation satellite system (GNSS), or real-time kinematic positioning (RTK) communication links.

Incidents

Two incidents occurred which resulted in service suspension:

- On August 16, during a demonstration run before launching public service, a shuttle was exiting a stop when its wheels traversed an adjacent curb. No injuries were reported. An investigation revealed that the rear LiDAR devices were mis-calibrated. To mitigate future issues, Beep implemented a daily pre-service test loop prior to the start of daily operations. After the LiDAR was recalibrated and testing was complete, the shuttle was reintroduced to the fleet and resumed service.
- On August 23, a shuttle was involved in a low-speed collision that resulted in minor cosmetic damage to both vehicles. No injuries were reported. There were no passengers on the shuttle and both vehicles were driven from the scene without assistance. The Beep shuttle had the right of way, while the other vehicle proceeded to make a left turn through the intersection after "rolling" a stop sign. Beep determined that the shuttle detected and maintained awareness of the other vehicle and performed a hard breaking maneuver prior to the collision. However, when the other vehicle failed to yield, the shuttle operator failed to engage the emergency stop button. Beep implemented various new procedures following the crash to enhance safety. Once these improvements were made and testing was complete, service resumed on September 10.

OUTREACH

Survey Findings

TIMMA conducted an online survey to solicit feedback from people who rode or encountered the shuttle. A total of 80 people provided survey responses. Of the 80 responses received, 32 respondents stated that they rode the Loop, and 32 stated that they did not ride the Loop. Most riders reported a positive experience using the shuttle, but provided more mixed views on the shuttle's reliability. Before riding, most riders believed that the shuttles were either somewhat safe or very safe. After riding the shuttle, nearly all believed that the shuttles were either somewhat safe or very safe. The majority rode the shuttle for the unique experience. Most respondents would have chosen to walk to their destination if they did not ride the shuttle.

Lessons Learned

The pilot yielded valuable insights and lessons learned for future AV shuttle pilot efforts:

CHALLENGES WITH PROCUREMENT

There are a limited number of operators and manufacturers that offer a shared AV solution, which limits the competitiveness of the procurement process. With the limited number of AVs available for use in the industry, TIMMA considered if prospective vendors could deliver, test, and commission vehicles in a timeline that did not conflict with other pilots across the US, if the provided vehicle could demonstrate a shuttle service by carrying a higher number of passengers, and the accessibility and experience for wheelchair users.

INCIDENT MANAGEMENT AND RESPONSE

With regular service disruptions, Beep and TIMMA staff worked collaboratively to establish procedures to review incident reports, develop mitigation strategies, and provide timely public notices. TIMMA developed a standard operating procedure (SOP) to establish procedures for testing and returning a vehicle to service following an incident.

UNRELIABILITY OF TECHNOLOGY AND SERVICE

All three shuttles experienced issues with their light detection and ranging (LiDAR) devices, resulting in extended outages of one or more shuttles. Moreover "signal loss" was an ongoing issue during the pilot. Sponsors need to ensure providers make spares available and emphasize the pilot nature of the service with the public.

COMPLEX OPERATING ENVIRONMENT

The island environment was relatively low density and low-volume/speed, however there were major construction activities/site conditions in the area throughout the pilot. This may have contributed to high shuttle disengagement rates and ultimately led to early termination of the Loop pilot, due to changing road conditions beyond the control of TIMMA and Beep.

UNIQUE STAFFING AND RESOURCING REQUIREMENTS

TIMMA Staff managed the project with consultant support. However, the level of involvement required throughout the planning, procurement, permitting, testing, and operational phases exceeded initial staffing estimates. Additional staffing resources for on-board operators would have also helped to minimize service disruptions due to absences and breaks.

DEMAND EXISTS FOR FIRST AND LAST MILE SOLUTIONS

Overall, the project showed in many ways that the demand for first and last mile solutions exists. Throughout the project, the local community was actively engaged and interested in learning more about a new way to travel around Treasure Island. Additionally, the community largely shared that they had a positive experience with the AV service. However, the pilot demonstration also showed that shared AV technology still requires improvements to become a more reliable and convenient mode of travel.

CONTRACTING FOR RISK MANAGEMENT

This pilot utilized a milestone-based contract that set target levels for service to be delivered as well as requirements for data reporting, testing, training, etc. It did not anticipate the level of missed service or equipment repairs that occurred during the pilot. The ultimate level of service interruptions and repairs for the pilot required a significant amount of project management time and negotiation by both TIMMA and Beep, which could potentially be mitigated in the future by employing some additional contracting strategies.

In order to ensure efficient coordination and management of operational risk, the operating agreement should be specific about the details of service delivery, e.g., number of vehicles dedicated to the project, recovery/contingency plans for prolonged service outages, and requirements to procure and clear consequences for protracted periods of missed service.

A milestone-based contract has advantages for this type of pilot project as it provides some protection against performance issues and benefits for the provider to have flexibility/discretion in how to deliver the service; namely, an agency does not have to pay for work until milestones are satisfactorily completed. This type of contract also benefits the provider, allowing flexibility and discretion in delivering the service. Well-specified milestone-based contract structures are appropriate / should be considered for future operating agreements.

1. Introduction

In August 2023, the Treasure Island Mobility Management Agency (TIMMA), in collaboration with the San Francisco Municipal Transportation Agency (SFMTA), and the Treasure Island Development Agency (TIDA), launched operations of the Treasure Island Shared Autonomous Vehicle (AV) Pilot Project. The project, known as "the Loop," was among the first pilots in California to demonstrate shared AV shuttle service on public roads. Initially, the project was intended to be a nine-month demonstration. However, due to evolving road conditions on the island, passenger service concluded after approximately four months. The project was funded by the Transportation Authority's Proposition K transportation sales tax program, the Federal Highway Administration's (FHWA) Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant program, and the Metropolitan Transportation Commission's (MTC) Innovative Deployments to Enhance Arterials (IDEA) grant program.

1.1 PURPOSE OF DOCUMENT

The purpose of this report is to document the implementation phase of the project, evaluate the operational phase of the project, and share lessons learned with peer agencies seeking to deploy shared AV technology. The report is divided into the following key areas:

- **Project Summary:** A summary of the project, including its path to implementation and the four months of operations where passenger service was provided
- **Mobility:** an evaluation of shuttle ridership, including a summary of shuttle accessibility for passengers who require mobility assistance
- **Operations:** an evaluation of overall vehicle performance and use
- **Safety:** an evaluation of shuttle incidents, disengagements, and improvements that were made to improve passenger safety
- **Outreach:** an overview of community outreach, partnership efforts, and an evaluation of feedback received from the community, highlighting the public's experiences and perception of the Loop
- **Lessons Learned:** a summary of the lessons learned during the deployment, highlighting operational and technology considerations for peer agencies seeking to deploy a shared AV

Figure 1-1. The Loop AV Shuttle

2. Project Summary

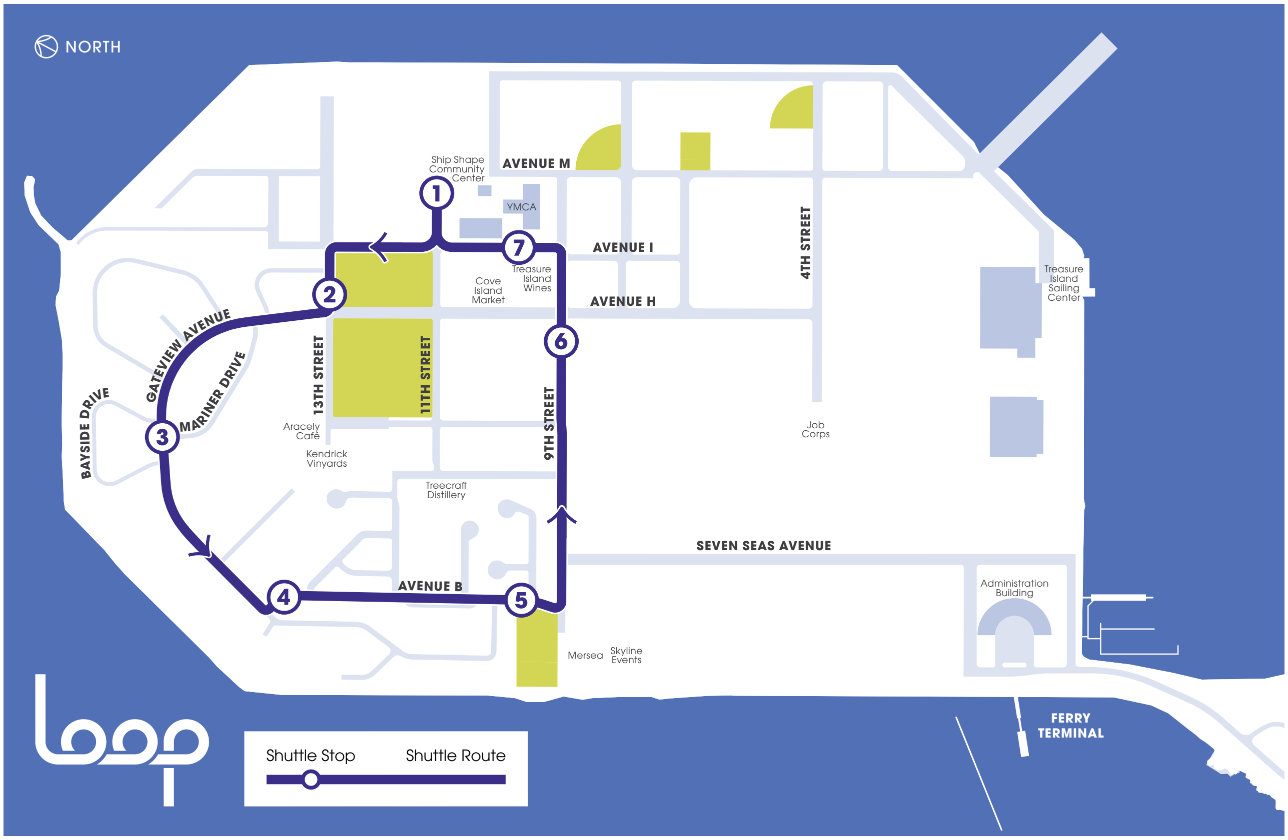
The Loop provided a free, shared AV shuttle service for residents and visitors of Treasure Island from August to December 2023. The Loop operated daily from 9 a.m. to 6 p.m., approximately every 30 minutes along a one-way route consisting of seven stops, as shown in Figure 2-1. With the intent of supporting intra-island trips, the Loop provided free passenger service along a 1.5-mile route through the center of Treasure Island, connecting residential areas, local businesses, and on-island services. The route paralleled the Muni 25 Treasure Island bus route, which provides service between Treasure Island and downtown San Francisco every 15 to 20 minutes. The Loop was initially planned to provide connectivity to the Treasure Island Ferry Terminal as a key transfer to Downtown San Francisco and local and regional transit. However, due to permitting issues that are discussed in the following section, the route was adjusted, and the Treasure Island Ferry Terminal stop was removed.

The Loop used two Gaussin Macnica Mobility (GMM, formerly Navya) AV shuttles[1] operated by Beep, Inc. (Beep), an autonomous mobility service company responsible for overseeing the implementation and operations. The shuttles supported Level 3 vehicle autonomy[2] and always had an on-board attendant to navigate stop-controlled intersections, assist passengers, and deploy manual ramps to support rider accessibility. The shuttles accommodated up to 10 passengers or eight passengers and one wheelchair. The fully electric shuttles were powered by an onboard battery unit and, during non-operational periods, were parked at a storage facility located on Treasure Island, approximately two blocks off route. The facility had in-wall charging, a satellite downlink terminal to support signal connection to the vehicle, and maintenance equipment.

1 A third AV Shuttle was included in the pilot as a backup vehicle, as needed.

2 https://www.epa.gov/greenvehicles/self-driving-vehicles

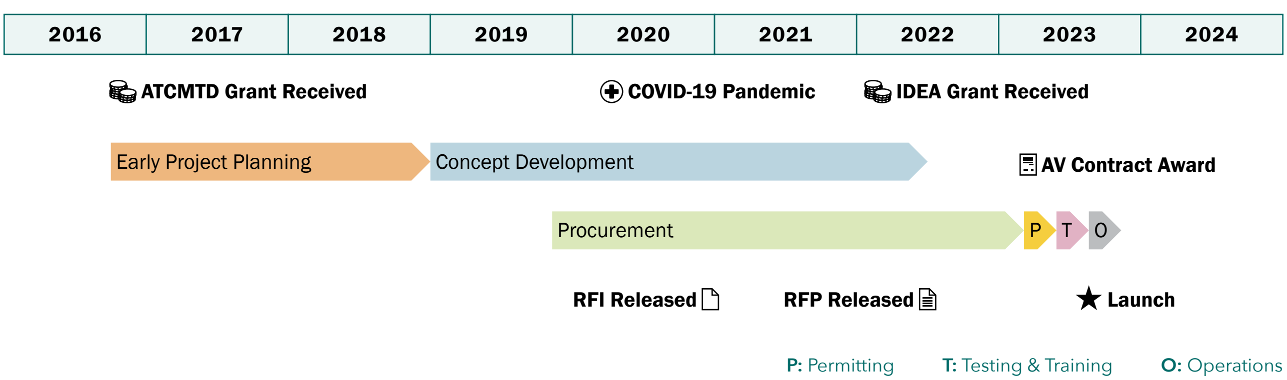
Figure 2-1. The Loop Route



2.1 IMPLEMENTATION

The following section provides a summary of the key activities that supported the eventual launch of passenger service for the Loop. To provide context on the length of time that passed from the project's early origins to the launch of operations, a timeline of the project's implementation phase is shown below.

Figure 2-2. Timeline to Project Implementation



2.1.1 Project Origin and Funding

SFMTA, in collaboration with the Transportation Authority, TIMMA, and other local partners, was awarded a U.S. Department of Transportation (USDOT) "Smart City" grant in 2016.[1] Administered by the FHWA, the grant program sought to showcase technology solutions aimed at reducing traffic congestion and creating safer and more efficient transportation systems. TIMMA partnered with SFMTA to propose testing and deployment of shared AVs on Treasure Island. The goal was to demonstrate clean, shared, and accessible first/last-mile autonomous shuttle transportation on Treasure Island, and to assess technical performance and public perceptions of the novel service. TIMMA, as the lead transportation agency overseeing Treasure Island's transportation program, led the implementation of the Loop.

In addition to the federal grant, the Transportation Authority provided local Proposition K transportation sales tax funds to support the planning, procurement, implementation, and administration of the project. In February 2022, TIMMA also received an award for the MTC Innovative Deployments to Enhance Arterials Shared Automated Vehicles (IDEA SAV) grant program to extend the Loop deployment from a three-month deployment to a nine-month deployment. The IDEA SAV grant also provided funds to support additional community outreach efforts, including local partnerships to engage local labor and educational institutions.

2.1.2 Early Project Planning

TIMMA collaborated with project stakeholders to develop a path towards project implementation. This proved to be challenging due to the complex nature of Treasure Island's redevelopment project. Currently, Treasure Island is being transformed into a mixed-use neighborhood with 8,000 new homes, 27% of them affordable, significant infrastructure improvements, and new street grid. This effort, led by TIDA, created significant on-island construction activities, including the complete rebuilding of roads. For the project to advance, TIMMA led agency coordination with TIDA and SFMTA to align efforts among the Loop service implementation, island construction, and 25 Treasure Island bus service.

To effectively progress from early planning to implementation, TIMMA led ongoing coordination with first responders, federal and state agencies, and SFMTA to ensure the safety of all road users and the public. TIMMA also helped Beep obtain all necessary insurance, state and federal permits (described further in Section 2.1.5), and coordinated project requirements with each funder, respectively.

1 Advanced Transportation and Congestion Management Technologies Deployment

Table 2-1. Project Stakeholders

Planning & Implementation	**Treasure Island Mobility Management Agency (TIMMA):** The agency responsible for implementing transportation demand management strategies to support the development of Treasure Island. **Treasure Island Development Authority (TIDA):** A non-profit public agency solely dedicated to the economic development of Treasure Island. **San Francisco Municipal Transportation Agency (SFMTA):** The local transportation agency that develops and oversees transit and parking services throughout San Francisco. The agency is also the recipient of the ATCMTD grant. **One Treasure Island (OTI):** A local 501(c)3 public charity that provides pathways for economic advancement for lower-income Treasure Island residents. This includes providing employment services for hiring on-board AV attendants.
Emergency Services	**San Francisco Police Department (SFPD):** The local law enforcement agency. **San Francisco Fire Department (SFFD):** The local fire and emergency response provider. **Admiral Security Services:** A private security firm that employs security officers who patrol Treasure Island. Often, these security officers are the first to arrive on scene.
Permitting	**National Highway Traffic Safety Administration (NHTSA):** A federal agency within USDOT focused on transportation safety. The agency is also responsible for providing operating waivers to autonomous vehicle vendors. **California Department of Motor Vehicles (CA DMV):** A state agency responsible for registering motor vehicles and issuing driver licenses in California. The agency is also responsible for issuing permits to manufacturers that test and deploy autonomous vehicles on California public roads. **California Public Utilities Commission (CPUC):** A state agency responsible for regulating privately owned utility companies, including passenger transportation companies. The agency is also responsible for providing permits to provide autonomous vehicle transportation on public roads in California.
Funding Oversight	**Federal Highway Administration (FHWA):** The federal agency within USDOT that oversees and administers the ATCMTD grant program. **Metropolitan Transportation Commission (MTC):** The metropolitan planning organization in the San Francisco Bay Area that oversees and administers the IDEA SAV grant program. **San Francisco County Transportation Authority (SFCTA):** The county congestion management agency for San Francisco that administers local transportation sales tax funds (Prop K/Prop L). The agency also shares staffing with TIMMA.

2.1.3 Concept Development

The project team developed an initial Concept of Operations (ConOps) that outlined the proposed AV deployment. The ConOps, shared in Appendix D, provided stakeholders the opportunity to offer input on the project and created a unified vision by establishing the technical course for the eventual System Requirements, shared in Appendix E. Importantly, the ConOps stipulated that the project would procure and test an existing AV service, rather than develop original technology or equipment. Additionally, the ConOps included a route planning memorandum that was developed in coordination with SFMTA. This memorandum identified potential routes for the shuttle, considerations for stop locations, and minimum expected headways, as well as possible locations for a storage and maintenance facility. Furthermore, the ConOps explored the feasibility of providing AV service to both Yerba Buena Island and Treasure Island to test a range of slopes, grades, and operating conditions. However, it was ultimately determined that the operational design domain[1] of existing AV shuttles would be limited to supporting trips on Treasure Island only.

Concurrently, the project team developed an evaluation framework for the project that outlined the Loop's goals, objectives, and performance metrics. This evaluation framework served as the foundation of the evaluation and is illustrated in Table 2-2.

Table 2-2. Evaluation Framework

TI AV GOALS	TI AV EVALUATION OBJECTIVES	WEEKLY SUMMARY REPORT	MONTHLY SUMMARY REPORT	3-MONTH EVALUATION / 9-MONTH EVALUATION
Safety: Without risking safety, understand the public safety implications of an AV Shuttle.	**1A.** Protect the safety of passengers & road users in TI during pilot operations. **1B.** Explore whether AV shuttle technology can safely address the driving challenges of TI.	• Total # of Incidents (by type) • Total # of Incidents (by shuttle) • Total # of Disengagements (by cause) • Total # of Disengagements (by shuttle) • Total # of incidents involving first responders	• Total # of Incidents (by type and week) • Incidents Per Mile (by type and week) • Total # of Incidents (by shuttle and week) • Incidents Per Mile (by shuttle and week) • Total # of AV Shuttle Disengagements (by cause and week) • AV Shuttle Disengagements Per Mile (by cause and week) • Total # of AV Shuttle Disengagements (by shuttle and week) • AV Shuttle Disengagements Per Mile (by shuttle and week) • **Basic** Survey Findings related to Passenger Safety (total responses, share riders/non-riders, distribution favorable perception for riders/non-riders) • Summary of Incidents Involving First Responders (if any) • Map of GNSS Outages by Location"	• Total # of Incidents (by type and month) • Incidents Per Mile (by type and month) • Total # of Incidents (by shuttle and month) • Incidents Per Mile (by shuttle and month) • Total # of AV Shuttle Disengagements (by cause and month) • AV Shuttle Disengagements Per Mile (by cause and month) • Total # of AV Shuttle Disengagements (by shuttle and month) • AV Shuttle Disengagements Per Mile (by shuttle and month) • **Detailed** Survey Findings related to Passenger Safety (everything in Basic plus distributions of respondents, trends ,and recommendations) • Summary of Incidents Involving First Responders (if any) • Map of GNSS Outages by Location • Map of All Incidents by Location • Map of All AV Shuttle Disengagements by Location"
Mobility: Understand if AV Shuttle technology can meet TIMMA's intra-island transportation service needs at TI.	**2A.** Explore whether AV shuttle service can be accessible to everyone **2B.** Explore AV Shuttle's ability to meet the intra-island needs of users in TI.	• Total Ridership • Total # of ADA Ramp Deployments • Total # of Wheelchair Securements	• Total Ridership (by shuttle and week) • Total # of ADA Ramp Deployments (by shuttle and week) • Total # of Wheelchair Securements (by shuttle and week) • **Basic** Survey Findings related to Passenger Service (total responses, share riders/non-riders, distribution of answers by question)	• Total Ridership (by shuttle and month) • Total # of ADA Ramp Deployments (by shuttle and month) • Total # of Wheelchair Securements (by shuttle and month) • **Detailed** Survey Findings related to Passenger Service (everything in Basic plus trends and recommendations) • Map of Ridership Totals by Stop Location
Operations: Understand TIMMA's organizational capabilities and infrastructure needs to operate an AV shuttle.	**3A.** Explore whether AV shuttle technology can meet TIMMA's TI shuttle operation needs. **3B.** Explore whether AV shuttle technology can meet TIMMA's TI shuttle service needs and constraints.	• Total # of Service Miles Traveled (by shuttle) • Total # of Service Hours Traveled (by shuttle) • % Down Time Due to Disruptions (95% threshold) • Average Battery Life at End-of-Service (by shuttle)	• Total # of Service Miles Traveled (by shuttle and week) • Total # of Service Hours Traveled (by shuttle and week) • % Down Time Due to Disruptions (95% threshold) (by shuttle and week) • Average Battery Life at End-of-Service (by shuttle and week) • Average Headways (by Week and Time of Day) • Average Dwell Time (by Week and Time of Day) • Average AV Shuttle Speeds (by Week and Time of Day)	• Total # of Service Miles Traveled (by shuttle and month) • Total # of Service Hours Traveled (by shuttle and month) • % Down Time Due to Disruptions (95% threshold) (by shuttle and month) • Average Battery Life at End-of-Service (by shuttle and month) • Average Headways (by Month and Time of Day) • Average Dwell Time (by Month and Time of Day) • Average AV Shuttle Speeds (by Month and Time of Day) • Map of Average Dwell Time by Stop Location • Map of Average AV Shuttle Speeds Between Shuttle Stops

1 The operational design domain (ODD) is the operating condition under which a vehicle's automated driving system is designed for and can be safely engaged.

2.1.4 Procurement

Due to the rapidly evolving landscape of the AV industry, TIMMA utilized a two-stage procurement approach for vendor selection, issuing an initial Request for Information (RFI), followed by release of a Request for Proposals (RFP). The RFI solicited input from the industry on potential turnkey services to plan, design, deploy, test, operate, and evaluate the AV deployment.

Findings of this process shaped the project's RFP and reflected the cost effectiveness and public benefits of pursuing a longer deployment period than the originally anticipated three-month deployment period. Additionally, the use of ATCMTD federal grant funds meant that the selected vendor must comply with federal procurement policies, regulations, and procedures including the Americans with Disabilities Act (ADA), Drug-Free Workplace Act, Equal Employment Opportunity (EEO), Buy America requirements, federally mandated maintenance policies, and federal prevailing wage rates. TIMMA worked closely with FHWA to ensure compliance with all federal procurement policies.

A formal RFP was released to the industry in spring 2022. Following the competitive procurement process, TIMMA selected Beep as the vendor for the AV demonstration on Treasure Island.[1]

2.1.5 Permitting

Before the Loop could begin operations, Beep was required to obtain all necessary insurance and permits to operate the AV shuttle. This included:

- $5 million in (liability/collision) coverage per CA DMV requirements;
- NHTSA approval to conduct the pilot demonstration;
- CA DMV approval to test the shuttle on California roads; and
- CPUC approval to deploy the shuttle (carry members of the public).

NHTSA evaluated the proposed service, including the route, stop locations, and operational details. This process revealed operational and safety concerns with traveling on Seven Seas Avenue, the only road available that connects the Treasure Island Ferry Terminal to residential and business areas of the Island. As a newly constructed road, Seven Seas Avenue was designed as a "complete street" with narrow travel lanes, bike lanes, transit boarding platforms for in-lane boarding, and limited parking. The street did not have dedicated space to create a shuttle pullover area to allow other vehicles to pass if the slow speeds of the shuttle caused congestion.[2] As a result, the route was revised to avoid travel on Seven Seas Avenue which ultimately precluded serving the Ferry Terminal.

1 https://www.sfcta.org/events/treasure-island-mobility-management-agency-board-9

2 The shuttles have a max operating speed of 12 mph.

The CA DMV oversees a program that requires all companies that intend to test and deploy AVs on California public roads to apply for a permit. In addition to administering this permit, the CA DMV also provided clarification on Title 13, California Code of Regulations, Division 1, Chapter 1, Article 3.7 Section 227.26 (f), prior to the AV shuttle operations. Section 227.26 subdivision (f) prohibits charging passengers a fee for a ride, and the manufacturer from receiving compensation for providing rides to members of the public. The CA DMV clarified that this prohibition did not apply to the Loop because the project was a strategic partnership between TIMMA and Beep, where Beep's costs are reimbursed by TIMMA and where Beep provides free rides to the public.

The CPUC provides permits for public convenience, or to allow AV vendors to carry members of the public. Within the CPUC Code, Section 226, there is an exception from the requirement to possess a certificate of public convenience and necessity. The CPUC found that the Loop met these exception requirements because the passenger service was on a fixed route, operated fully within San Francisco, and did not have fare requirements. An exemption letter was provided to TIMMA, and the project was cleared to begin testing.

2.1.6 Reports and Deliverables

Throughout the permitting process, Beep was also required to develop several deliverables to support the operational phase of the project. This included a Safety Plan, Incident Response Plan, Cybersecurity Plan, Data Management & Sharing Plan, Reporting & Evaluation Plan, Testing Plan, Training Plan, and Operations & Maintenance Plan. The Safety, Cybersecurity, and Incident Response Plans outlined key procedures, mitigation strategies, and communication protocol to ensure the safety of all passengers, operations staff, and the public. The Data Management & Sharing and Reporting & Evaluation Plans outlined the processes for data collection, data transmittal, and reporting structure used throughout the operations phase. Lastly, the Testing, Training, and Operations & Maintenance Plans outlined the required testing, training, and operations and maintenance protocol to support the vendor's readiness for operations.

2.1.7 Testing and Training

Prior to launching service, TIMMA required Beep to conduct testing for a 30-day period. While this 30-day period was not required, TIMMA chose to adhere to AV testing recommendations provided by CPUC. Early on, Beep determined that two shuttles would be required to ensure ample battery capacity for daily operations. During the 30-day test period, Beep tested each vehicle for a minimum of five hours daily to reflect the planned service and ensure vehicle reliability and performance.

In Week 1, Beep mapped the shuttle route, trained on-board attendants, and conducted on-route testing to ensure the vehicle was navigating the route as programmed.

In week 2, Beep hosted field training workshops with first responders and SFMTA bus operators. The first responders training, which included SFPD, the SFFD, and Admiral Security, focused on emergency response planning, interfacing with the AV shuttle during live operations, and incident coordination. The training with SFMTA bus operators reviewed scenarios in which buses may interface with the AV shuttle during live operations. Though the two services did not share stops, the training also included executing various operational scenarios with an SFMTA test coach and the Loop shuttle to ensure both vehicles could operate along the route simultaneously, without conflict. The presence of on-board attendants on the Loop mitigated many of the concerns and risks identified by the first responders and SFMTA operators.

In week 3, Beep conducted a series of formal tests witnessed by the project team. These tests were guided by the project's System Requirements, and included several functional, operational, and stress tests to ensure all vehicles were prepared for live operations.

In week 4, Beep continued on-route testing and further refined the shuttle's readiness for live operations. After the completion of all testing and training, passenger service began.

2.1.8 Capital Improvements

Since the project was a short-term pilot demonstration, no significant capital improvements were made.[1] However, to support wayfinding and passenger safety, a small number of low-cost improvements were implemented along the route. This included the set-up of temporary signage at each stop location, as well as minor improvements to create a formal stop location at the Ship Shape Community Center, as shown below.

Figure 2-3. The Loop Stop Signage

1 The project added two vehicle charging outlets to the storage space, a satellite downlink terminal on the exterior of the storage space, and installed striping and tactile treatments at the Ship Shape Community Center shuttle stop.

Figure 2-4. Ship Shape Community Center Striping Improvements

2.1.9 Data Collection and Reporting

TIMMA established data collection requirements based on the project's goals and objectives and worked with Beep to ensure all data could be regularly collected during operations. Table 2-3 summarizes all data provided to the project team. Data exports from on-board vehicle equipment logs provided vehicle movement and location data. Other data (such as ridership by stop and time of day, wheelchair securements, ramp deployments, specific disengagement / incident report findings, and service disruptions) were collected manually by on-board attendants. Notably, at the start of operations, Beep did not have a process to collect ridership data by stop and time of day. This data was critical to further understand on-Island ridership trends and Beep developed a manual data collection process to record shuttle ridership as it occurred. Training on-board attendants, validating the accuracy of the data, and implementing quality control processes took several weeks to complete and was finalized in the second month of operations. In addition to the data provided by Beep, TIMMA conducted an online rider and non-rider survey.

To support ongoing operations, TIMMA also developed an ongoing reporting structure for the project, which included:

- **Weekly Reporting:** a weekly summary highlighting key operational metrics
- **Monthly Reporting:** a monthly summary report highlighting key operational metrics, including further details around vehicle performance and survey tracking
- **Final Evaluation Report:**[1] this report, which is an evaluation of the Loop at the conclusion of service

1 The project initially intended to develop a three-month and nine-month evaluation report. Due to the conclusion of operations in month 4, only one evaluation report was compiled.

2.1.10 Evaluation Methodology

The Evaluation Framework shared in Section 2.1.3 guided the evaluation of the Loop service. For additional information regarding the evaluation methodology used in this report, please see Appendix A.

Table 2-3. Data Collected During AV Deployment

Weekly Report	• Date, Name, Site, Shuttle, Route, Operator • Current Mileage, Loops Completed, Ridership • Starting, Ending Battery Charge % • Wheelchair Securements • ADA Ramp Deployments • Pedestrian, Weather, Congestion Conditions • Passenger Behavior and Other Logged Events
Weekly Hit Ratio Report*	• Date, Site, Shuttle, Route • Average Weekly Hit Ratio %
Weekly Ridership Report	• Date, Time, Name, Site, Shuttle, Route • Stop Station • Boardings, Alighting • Loop Number
Weekly Mechanical Report	• Date, Name, Route, Shuttle, Hit Ratio Validation • Equipment Validation: Key, Dash Cam, Camera PC, UI, AMD, AC, Suspension, Computers, Interior Lighting, Seating, Battery, Safety Equipment • Equipment Validation (contd.): ADA Equipment, Microfiber Cloth, External Displays, Tires, Rims, Windows, Exterior Sensors, Exterior Lights, Body, Charging Cable, Mobile Device
Weekly Disengagement Report	• Name, Site, Shuttle, Route, Time, Location, Weather • Vehicle Speed • Number of Passengers • Pedestrians, Other Vehicles, Other Road Objects Involved • Operating Mode, Initiated By • Cause, Cause Description
Weekly Incident Report	• Date, Site, Shuttle, Time, Location, Weather • Shuttle Operator, Operating Mode • Incident Type, Reported Injury • Medical Attention • Police, EMS/Fire, Media Involved • Vehicle Speed • Number of Passengers • Pedestrians, Other Vehicles, Other Road Objects, Witnesses Involved • Reported By • Cause, Cause Description • NHTSA Reportable

Monthly Vehicle Data	• Braking Events • Odometer • Speeds • Stops • Telemetry • Time
Monthly Availability Tracker	• Date, Shuttle • Service Impact • Reason for Downtime • Preventable, Non-Preventable
Survey Data (conducted & provided by TIMMA)	• Survey Responses in English, Chinese, Spanish, and Filipino

2.2 OPERATIONS

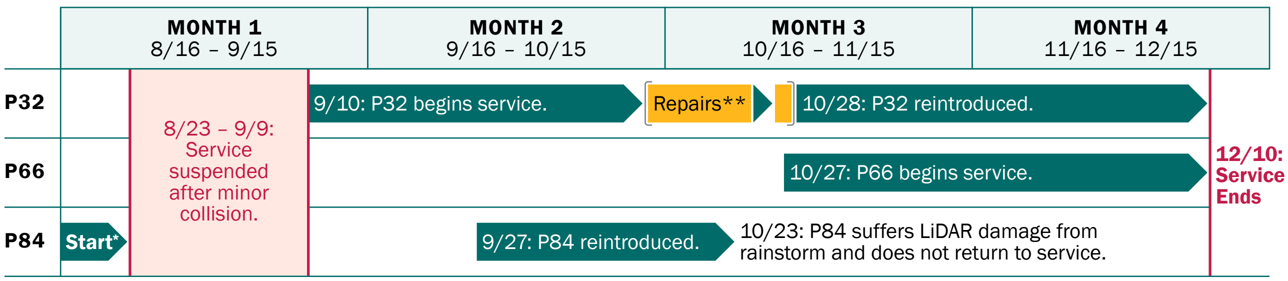
On August 16, 2023, the Loop began passenger service. During four months of operations, the Loop provided rides to 1,177 passengers. In total, the Loop's AV shuttles traveled over 3,015 miles across 1,050 service hours. During this time, the project employed on-board attendants through various local hire recruitment programs and platforms, while also providing opportunities for community members to engage with the AV shuttles through several outreach events (discussed further in Section 6.2). In addition, the project collected 80 online survey responses from members of the public. Generally, the survey responses pointed to a positive experience for both shuttle riders and non-riders.

Throughout the deployment, there were also several operational challenges that caused service up-time and reliability issues. These challenges ultimately caused multiple service disruptions, including a temporary shutdown of service and, later, the early termination of the pilot. Each of these instances are further described in Appendix B. Initially, the project intended to have two AV shuttles available to each provide five hours of service every day, with one hour of overlap. Due to the various service disruptions that occurred, a third shuttle was provided by Beep to support service continuity. The following is a summary of the service disruptions that caused the greatest impact to operations during the deployment:

- On August 23, 2023, one week after the launch of service, a shuttle was involved in a low-speed, non-injury collision (described further in Section 5.2). Service was suspended for approximately two and half weeks. After safety enhancements were incorporated and vehicle re-testing was complete, passenger service resumed on September 10, 2023.

- In October, one shuttle was removed from service due to on-going repairs, and another was removed from service due to LiDAR damage from a rainstorm (see Section 7.3).
- On December 10, 2023, service was suspended due to changes in the road configuration along 9th Street. TIMMA staff explored alternatives to complete the pilot, including a re-mapping of the new 9th Street configuration. However, due to schedule and cost impacts, it was ultimately determined that the pilot would conclude.

Figure 2-5. Loop Operations August – December 2023



* 8/16: Service begins with P84 only. P32 does not begin service due to curb strike. P66 remains in testing due to LiDAR issues.

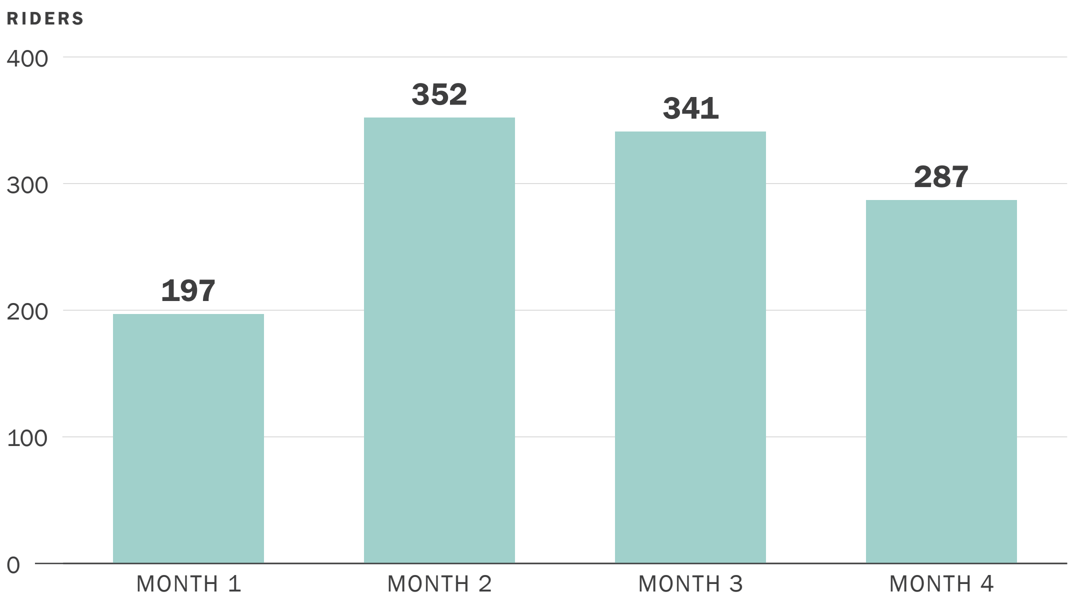
** 10/14 – 10/28: P32 undergoes repairs, is briefly returned to service, and undergoes further repairs until being reintroduced to service once again

3. Mobility: Understand if AV shuttles could meet the mobility needs of Treasure Island residents and visitors

3.1 RIDERSHIP

A total of 1,177 passengers boarded the Loop. Ridership peaked in Month 2 at about 350 riders and remained almost as high in month 3 (see Figure 3-1). Month 1 and month 4 had lower ridership due primarily to service interruptions. During month 1 service was suspended in the last two weeks due to a non-injury collision (see Section 5.2) and during Month 4 there was an early conclusion of service due to Island construction. Throughout the four months of operations, the highest weekly ridership total recorded was 111 passengers, which occurred in month 3 during late October/early November.

Figure 3-1. Monthly Ridership

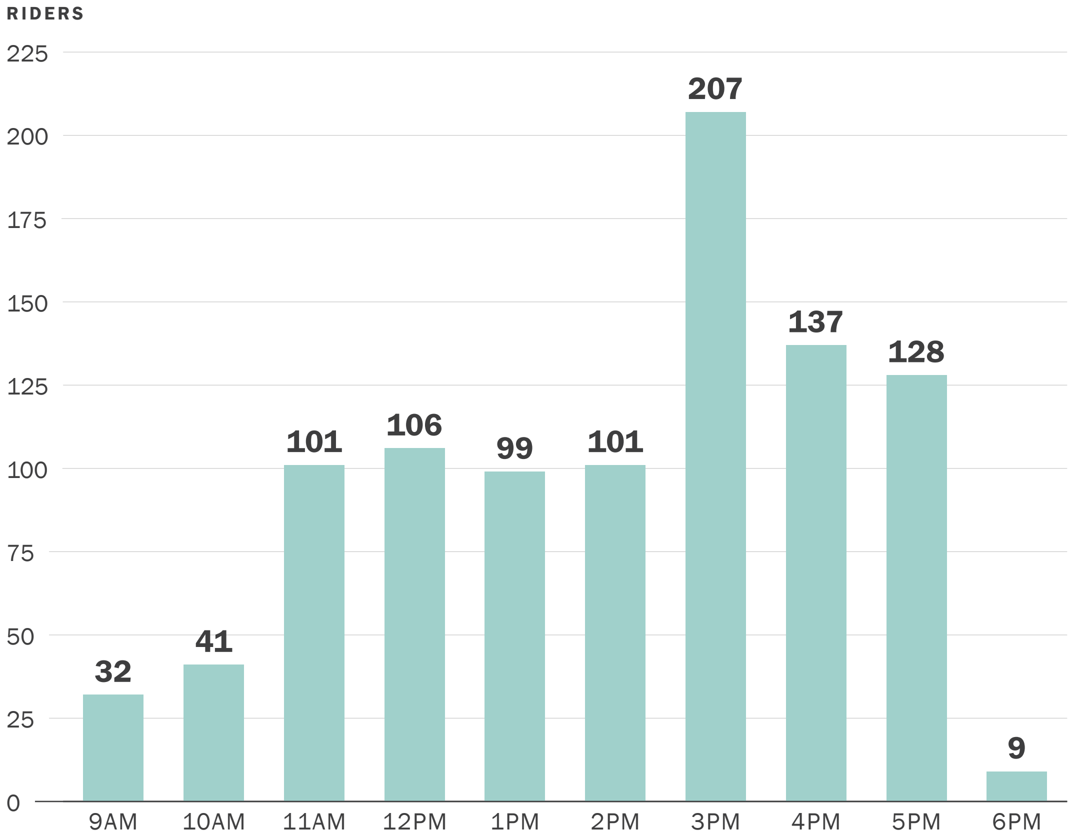


3.1.1 Detailed Ridership

Hourly ridership provides more detailed insights into passenger travel patterns.[1] As shown in Figure 3-2, between 2 p.m. to 6 p.m. emerged as the peak ridership time interval, accounting for 40% of service hours, but approximately 61% of ridership. The 3 p.m. hour had the highest concentration in ridership and ridership was lowest during the AM period.

1 Detailed ridership data was provided by Beep after the re-start of service on September 10. Therefore, hourly ridership totals may differ from the monthly totals provided in the prior section.

Figure 3-2. Hourly Ridership Across All Months



Ridership by stop is another opportunity to understand on-island travel patterns. This evaluation was done by reviewing overall stop boardings (locations where passengers entered the shuttle) and overall stop alightings (locations where passengers exited the shuttle).

As shown in Figure 3-3 and Figure 3-4, Avenue B at Chinook Court (near the Treasure Island Playground & Dog Park, the Mersea restaurant, and the nearest stop to the Treasure Island Ferry Terminal) was the most boarded and most alighted stop on the route. The Ship Shape Community Center was the second most boarded stop on the route. Avenue I at the YMCA was the least boarded and least alighted stop on the route.

In addition to being a local hub for community events, the Ship Shape Community Center also hosts a local food pantry on Tuesdays between 2 p.m. and 5 p.m. Detailed ridership data for this stop shows that 68% of all riders who boarded the Loop at the Ship Shape Community Center did so on Tuesdays between the 2 p.m. and 5 p.m. hours, a significantly higher proportion compared to ridership on other days of the week within that specific time frame.

Figure 3-3. Mapping of Stop Boarding Across All Months

Note: the Ridership Report by Stop was finalized in September 2023. Please note that ridership data prior to September has been omitted.

Figure 3-4. Mapping of Stop Alighting Across All Months

Note: the Ridership Report by Stop was finalized in September 2023. Please note that ridership data prior to September has been omitted.

3.2 ACCESSIBILITY

Vehicle accessibility ensures a seamless experience for passengers with mobility challenges. The Loop's shuttles had capacity for one wheelchair user and utilized a manually deployed ADA ramp to support boarding/alighting, if needed or requested. Shuttle operators manually recorded instances of ADA ramp deployments and wheelchair securements. Table 3-1 and Table 3-2 summarize the distribution of ADA ramp deployments and wheelchair securement during the pilot. Overall, a total of 18 ADA ramp deployments and 5 wheelchair securements occurred. The higher ADA ramp deployments compared to wheelchair securements is likely due to passengers who do not utilize wheelchairs, but still require mobility assistance to enter the AV shuttle (i.e., canes, walkers, or a wheeled device, such as a cart).

Table 3-1. Monthly ADA Ramp Deployments

	TOTAL
Month 1	1
Month 2	5
Month 3	7
Month 4	5
Total	**18**

Table 3-2. Monthly Wheelchair Securements

	TOTAL
Month 1	1
Month 2	3
Month 3	1
Month 4	0
Total	**5**

4. Operations: Understand the capabilities, infrastructure, and operational needs that are required to operate an AV shuttle

4.1 OPERATIONAL PERFORMANCE

The following metrics are evaluated in this section to assess the pilot's ability to provide prompt passenger service:

- **Headways:** the average time interval between shuttles arriving at a stop location
- **Dwell Times:** the average time shuttles are stopped at locations to pick up/drop off passengers
- **Shuttle Speeds:** the average speed of the shuttle traveling between stop locations
- **Service Uptime:** the ability for the shuttle vendor to provide ongoing passenger service

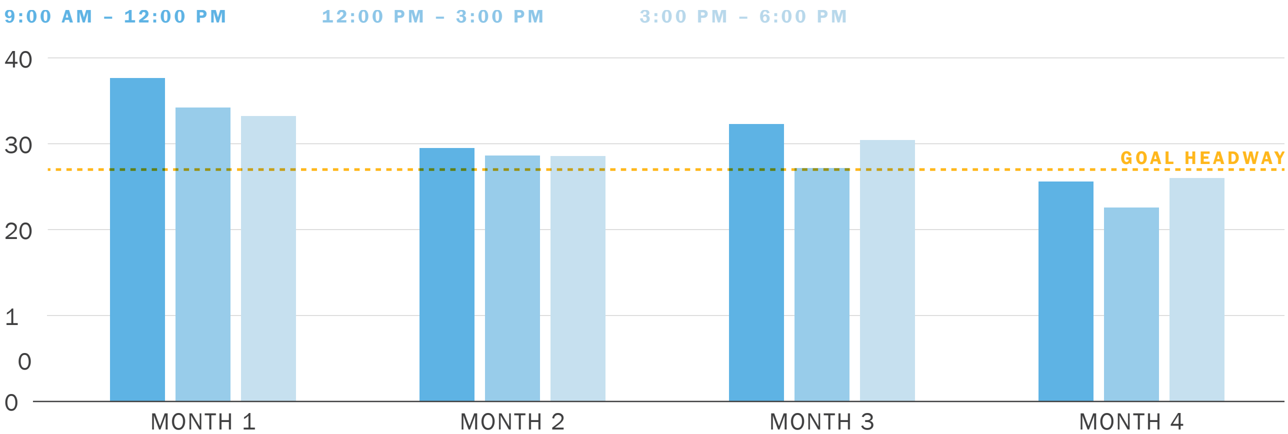
Each of these metrics are influenced by stoppages that occur along the route due to operator shift swaps, breaks (required by state law; these are often lengthy when only one shuttle is cleared to operate on the route), and external circumstances resulting in shuttle disengagements (e.g., the presence of other road users or objects that are in the shuttle's path). For additional context around these issues, see Section 5.1.

4.1.1 Headways

Headways for each month, by time of day, are shown in Figure 4-1. The time-of-day periods are defined by an AM period (9 a.m. – 12 p.m.), midday period (12 p.m. – 3 p.m.), and PM period (3 p.m. – 6 p.m.). The pilot aimed to achieve an operational goal of an average of 27-minute headways. Consistently meeting the goal of 27-minute headways did not occur until month 4, when two shuttles were consistently in service. During month 1 headways consistently exceeded 30 minutes across all time periods, almost reaching 40 minutes in the AM period. This is likely attributable to the availability of only one shuttle during this time. Headways decreased during month 2 because of the reintroduction of previously inactive shuttles. In month 3, several shuttles required maintenance and were pulled from service, resulting in longer headways. In month 4, after shuttles were repaired and the project overcame prior operational challenges, the 27-minute headway goal was achieved.

Across all months, headways were often shorter during midday operations. This is likely due to the one-hour time block (12 p.m. – 1 p.m.) when, if possible, two shuttles operated simultaneously.

Figure 4-1. Average Headways in Minutes by Time of Day

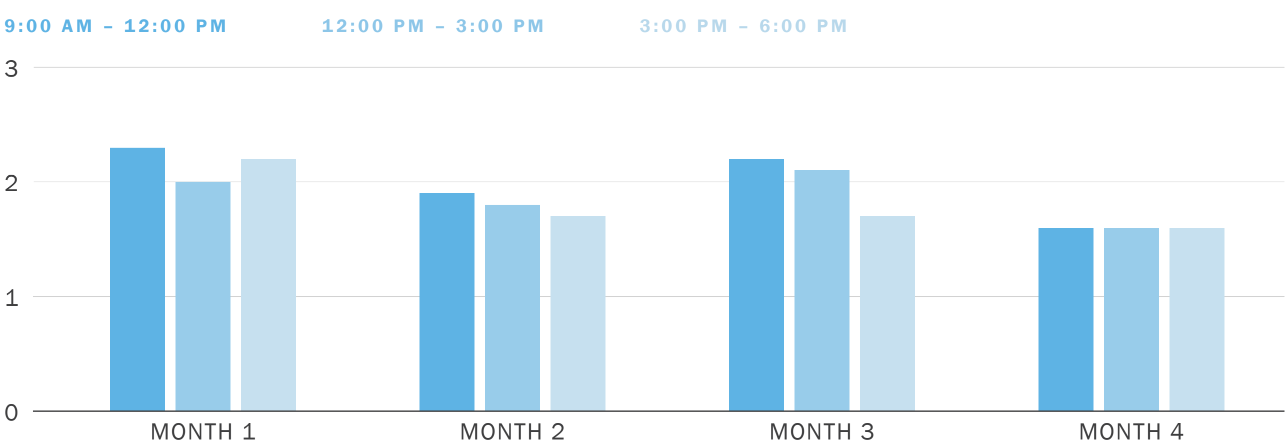


4.1.2 Dwell Times

Route-wide dwell times for each month, by time of day, are shown in Figure 4-2. Route-wide dwell times typically averaged between 1.6 to 2.3 minutes, which is high given the Loop's ridership.[1] Long dwell times are reflective of the time on-board operators take to engage riders/answer questions, communicate status reports to Beep's Command Center, and submit reports when necessary. Overall, route-wide average dwell times dropped below two minutes in Month 4.

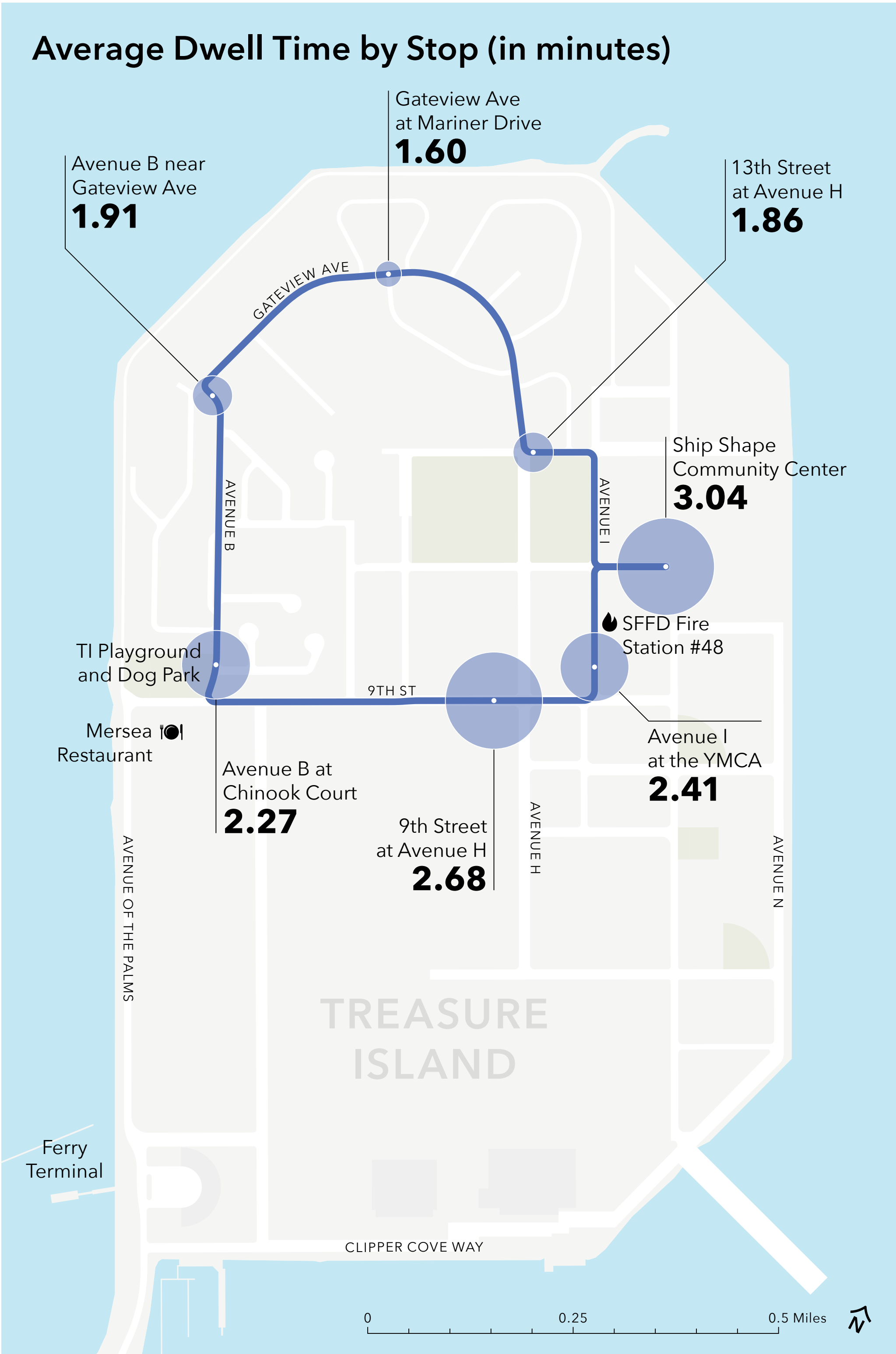
Figure 4-3 shows the average dwell times by stop. The longest average dwell times were at the Ship Shape Community Center, 9th Street at Avenue H, and Avenue I at the YMCA. Beep noted that shift swaps and operator breaks (when required) occurred near the YMCA and Ship Shape Community Center stop locations, which is reflected in these longer dwell times.

Figure 4-2. Route-wide Average Dwell Times in Minutes by Time of Day



1 In a hypothetical scenario where Muni buses are serving the same volume of Beep's recorded boardings and alightings, estimated dwell times for Muni would be closer to 10 seconds, on average.

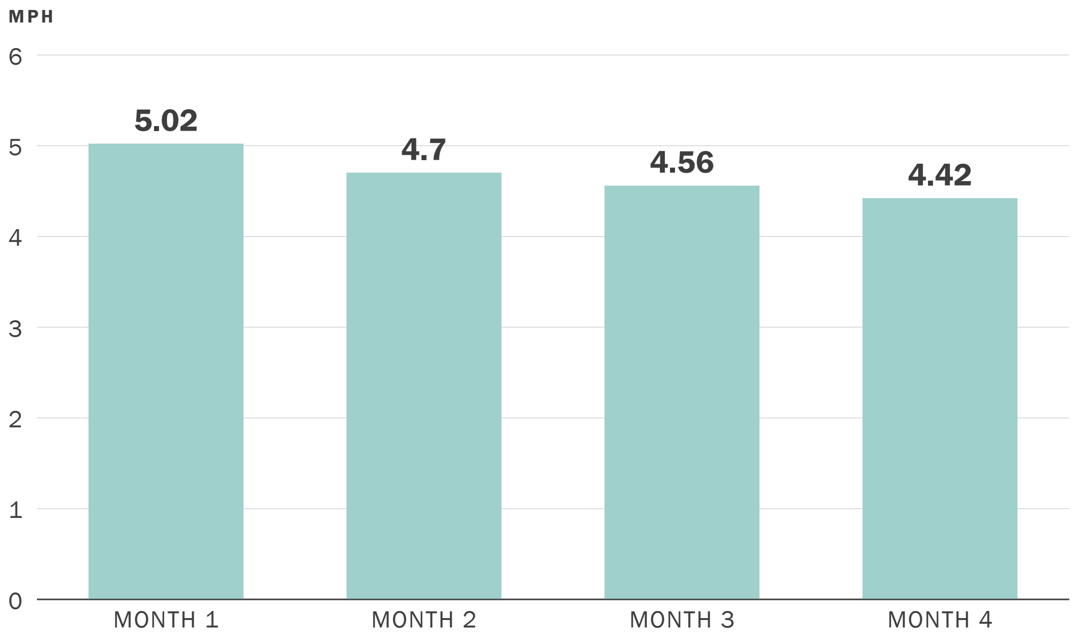
Figure 4-3. Average Dwell Times in Minutes by Stop Location



4.1.3 Shuttle Speeds

Shuttles maintained an average speed between four and five miles per hour (MPH) during the pilot. While the shuttles are permitted to travel at a maximum speed of 12 MPH along the route, average speeds are impacted by stop-controlled intersections and shuttle disengagements associated with the presence of other road users. During disengagements, the operator is required to engage manual mode, move the vehicle, and reengage autonomous mode, which happens in a short sequence at low speeds. A notable trend is a steady decrease in average shuttle speed month over month. This decrease in shuttle speed may be associated with an increased frequency of shuttle disengagement occurrences month over month, which is discussed further in Section 5.1.

Figure 4-4. Average Monthly Shuttle Speed in MPH



4.1.4 Service Uptime

Service uptime is defined as the percentage of time the shuttles were able to provide passenger service. The project set a goal of an average monthly service uptime of 95%. In this report, service uptime is evaluated in three ways:

- **Expected Runs Completed:** Illustrates Beep's ability to finish 22 loops around the Island daily. Expected Runs Completed is calculated assuming 27-minute headways are achieved during operational hours.
- **Expected Miles Traveled:** Illustrates Beep's ability to travel 33 miles daily. Expected Miles Traveled is calculated assuming Beep completes 22 loops daily, with each assumed to be approximately 1.5 miles.

- **Expected Hours Traveled:** Illustrates Beep's ability to provide passenger service from 9 a.m. to 6 p.m. daily. Expected Hours Traveled is calculated assuming passenger service is provided for nine hours, with a one hour overlap during midday where two vehicles are operating, equaling a total of 10 hours daily.

As shown in the following tables, there were challenges in providing sufficient service in month 1, which is mostly attributed to the suspension of service that occurred due to the non-injury collision (discussed further in Section 5.2). However, in the following months, as shuttles began to return to service, service uptime generally improved. Month 3 saw a dip in service reliability, which was likely caused by the hardware and LiDAR issues that caused several vehicles to be pulled from service intermittently (discussed further in Section 7.3).

Table 4-1. Expected Runs Completed

	TOTAL RUNS COMPLETED	EXPECTED RUNS COMPLETED	% RUNS COMPLETED
Month 1	206	682	30%
Month 2	609	645	94%
Month 3	598	682	88%
Month 4	560	528	106%
Total	**1,973**	**2,537**	**78%**

Table 4-2. Expected Miles Traveled

	TOTAL MILES TRAVELED	EXPECTED MILES TRAVELED	% MILES TRAVELED
Month 1	355	1,023	35%
Month 2	932	967	96%
Month 3	911	1,023	89%
Month 4	817	792	103%
Total	**3,015**	**3,805**	**79%**

Table 4-3. Expected Hours Traveled

	TOTAL HOURS TRAVELED	EXPECTED HOURS TRAVELED	% HOURS TRAVELED
Month 1	119	310	38%
Month 2	328	293	112%
Month 3	322	310	104%
Month 4	281	240	117%
Total	**1,050**	**1,153**	**91%**

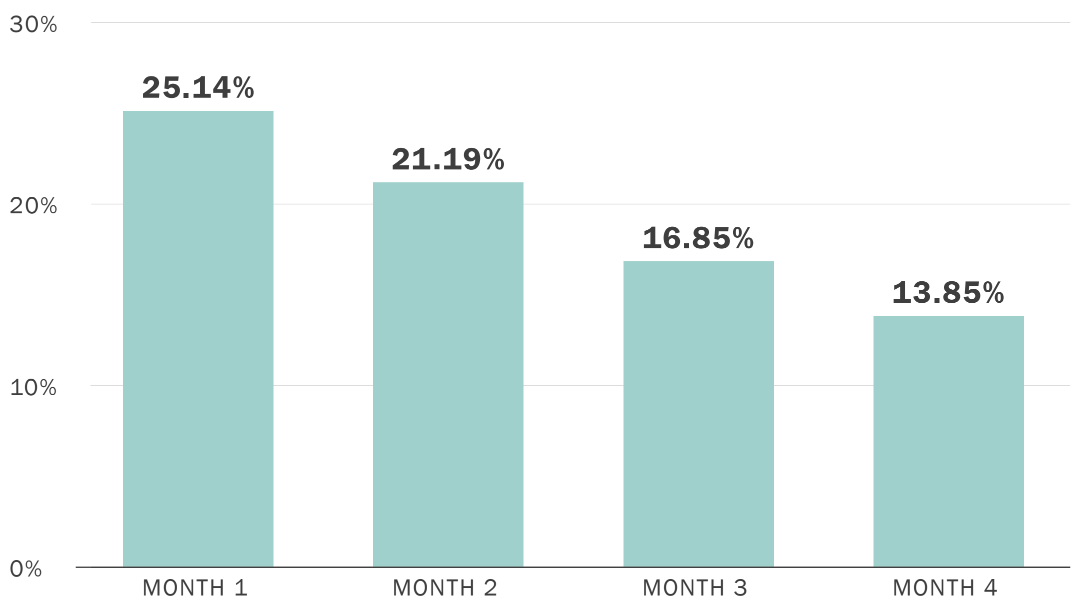
Overall, Beep did not consistently achieve an average monthly service uptime of 95%. As discussed above, service uptimes were adversely impacted when vehicles were pulled from service. When only one vehicle was operating on the route, shift changes and operator breaks created gaps in service and two shuttles could not operate during the 12 p.m. – 1 p.m. hour. There were also several documented instances where AV shuttle operators called in sick or missed a shift, impacting service uptime for several hours, and, in some instances, the entire day.

4.1.5 Battery Usage

The all-electric shuttles were charged at an on-Island storage facility overnight and started each day with 100% battery. Beep established a minimum threshold of 30% battery, at which point vehicles would need to be charged. Initially, two shuttles were recommended for the project to ensure sufficient battery range for daily operations. Concerns about vehicle reliability raised questions on whether a single shuttle could operate for the full-service period (9 a.m. – 6 p.m.) on a single charge, if needed. As shown in Figure 4-5, on average, a typical staff shift depleted[1] between 15% and 25% of the vehicle's battery life. On most days, two to three staff shifts were required to provide passenger service from 9 a.m. to 6 p.m., and the lowest recorded battery life at the end of a staff shift was 34%. There were no recorded issues directly attributable to battery capacity.

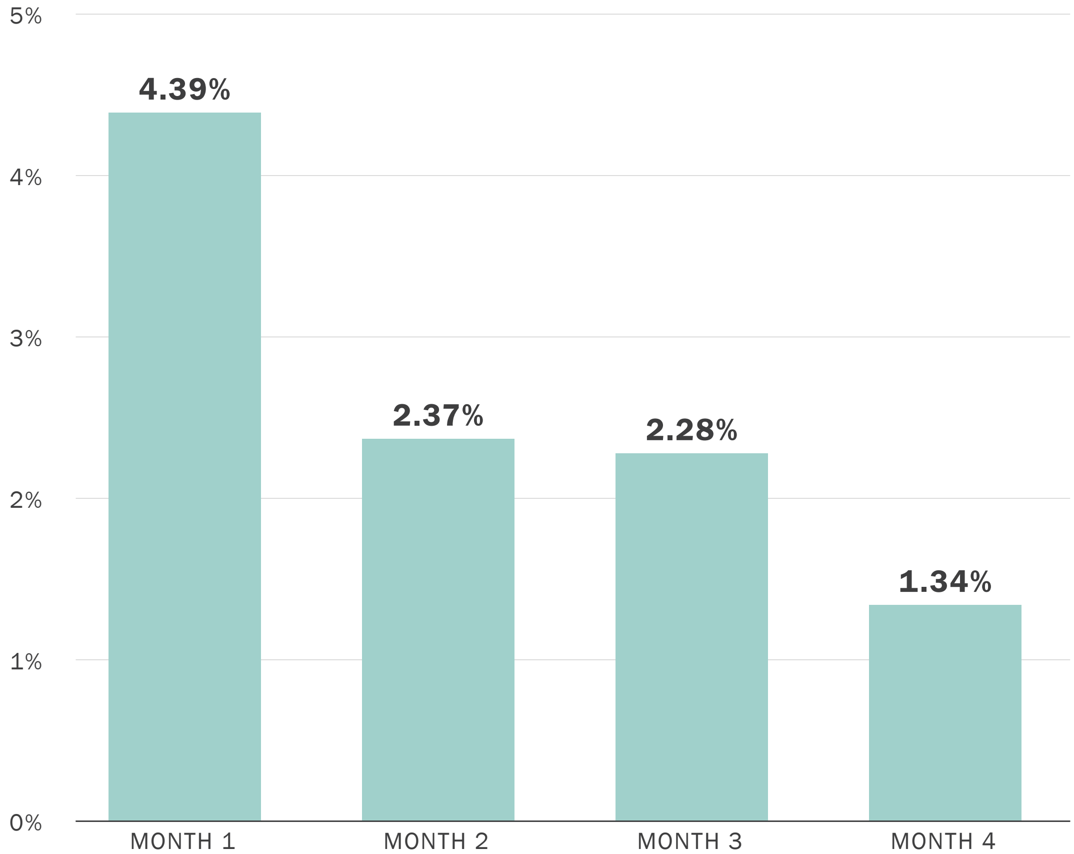
As shown in Figure 4-5, there was also a consistent, month over month decline in the average battery depletion per staff shift. This is likely attributable to the concurrent operation of multiple shuttles in the later months, which allowed shift operators to use a single vehicle for shorter periods of time. Figure 4-6 shows battery depletion by loop decreased month over month. Specifically, the average battery depletion per loop nearly halved, decreasing from 4.4% to approximately 2.3% in months 2 and 3 and approximately 1.3% in month 4.

Figure 4-5. Monthly Average Battery Depletion % per Shift



1 Battery depletion is defined as the difference between the starting and ending battery charge of a vehicle at the conclusion of a staff shift or loop.

Figure 4-6. Monthly Average Battery Depletion % per Loop



5. Safety: Understanding the public safety implications of operating an AV shuttle

5.1 DISENGAGEMENTS

Disengagements are instances where the AV disengages autonomous mode and requests manual operation from the shuttle on-board operator. While not inherently a safety issue, disengagements can occur for a variety of reasons, as shown in Section 5.1.1. Additionally, many shuttle disengagements are a result of the AV determining that a particular driving environment is beyond the vehicle's ODD.

5.1.1 Definitions of Disengagement Causes

Fault Code/Error Code

Fault Code/Error Code prevented the shuttle from autonomous operation. Shuttle attendant navigated in manual mode to the next safe stop location to troubleshoot.

Obstacle Detection

An object was detected within the path and prevented autonomous operation. Shuttle attendant navigated around obstacle in manual mode and returned to autonomous mode.

Other Road Users

A vehicle was detected as an obstacle due to close proximity to the shuttle's path. Shuttle attendant navigated around vehicle in manual mode and returned to autonomous mode.

Priority Zone

A(n) object/pedestrian/vehicle was detected within the priority zone and prevented autonomous operation. Shuttle attendant navigated around obstacle in manual mode and returned to autonomous mode.

Shuttle Manually Deviated from Approved Path

Shuttle attendant operated manually outside of the NHTSA approved path.

Signal Loss

Shuttle lost signal 5G/GNSS/RTK and was unable to continue in autonomous mode. Shuttle attendant navigated in manual mode until signal strengthened, then resumed in autonomous mode.

Station Blocked

Station was blocked, preventing autonomous operation into/out of the designated stop station. Shuttle attendant navigated in manual mode to stop, then resumed in autonomous mode.

Vegetation

Vegetation prevented autonomous operation.

Vulnerable Road Users

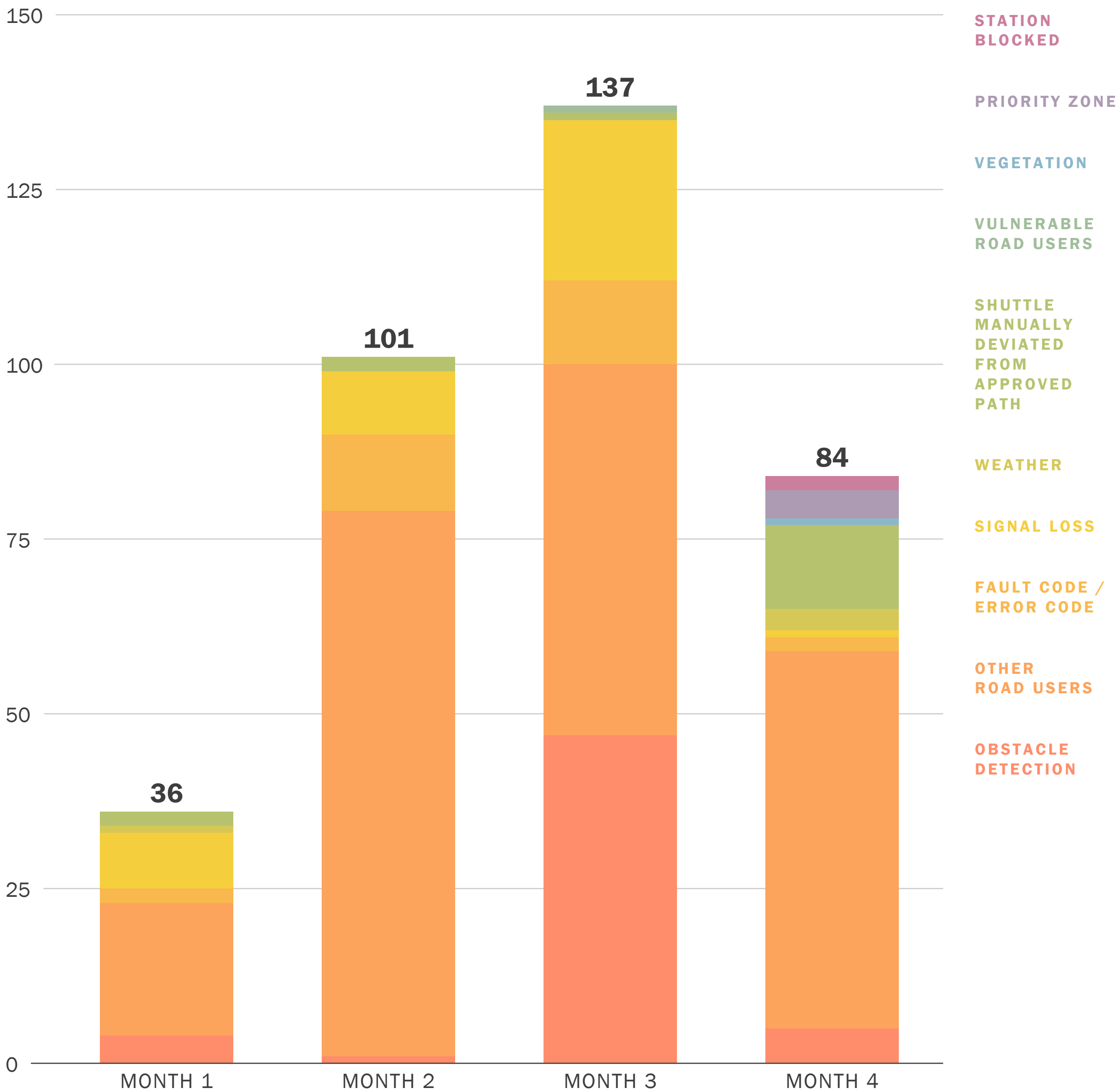
A vulnerable road user (VRU) interacted with the shuttle preventing autonomous operation. Shuttle attendant navigated in manual mode, then returned to autonomous mode.

Weather

Weather prevented autonomous operation.

As shown in Figure 5-1, there were a total of 358 shuttle disengagements during the pilot, with "Other Road Users" as the predominant cause, representing 57% of the total disengagements reported. The second highest cause was "Obstacle Detection," which represented 16% of all disengagements. This cause is followed by "Signal Loss," "Fault Code/Error Code," "Priority Zone," "Shuttle Deviated from Approved Path," "Station Blocked," "Vegetation," "Vulnerable Road Users," and "Weather," which accounted for the remaining shuttle disengagements. Each of these causes of disengagement is evaluated further in the following sections.

Figure 5-1. Monthly Shuttle Disengagements by Cause



As shown in Figure 5-1, the total number of disengagements increased between Month 1 and month 2, in part due to suspension of service in month 1. Disengagement increased again in month 3, including notable increases in "Obstacle Detection" and "Signal Loss." Disengagements then dropped in month 4 due to the early conclusion of service.

5.1.2 Other Road Users

Figure 5-2 illustrates the location of "Other Road User" disengagements. These instances occurred throughout the route, with notable exceptions along 9th Street between Avenue H and Avenue C, and on Avenue B between 9th Street and 12th Street. There are also two noticeable areas of concentration: near the fire station located along Avenue I, and along Avenue B, south of the Avenue B-Gateview Ave stop. The fire station is known to have a high concentration of emergency vehicles parked near the station entrance, which may have caused regular disengagements requiring re-routing the shuttle around the parked vehicles. The other location, along Avenue B, is a narrow single-lane road in a residential area that is known to have a high concentration of parked vehicles and the shuttles likely required manual operation to re-route around parked vehicles.

Figure 5-2. Mapping of "Other Road Users" Disengagements

5.1.3 Obstacle Detection

Figure 5-3 illustrates the location of "Obstacle Detection" disengagements. There is a concentration of instances occurring north of the 13th Street at Avenue H stop. Several of these instances occurred in early November and are likely attributable to the road construction that took place on this stretch of road.

Figure 5-3. Mapping of "Obstacle Detection" Disengagements

5.1.4 Signal Losses

Figure 5-4 illustrates the location of "Signal Loss" disengagements. As shown, these are concentrated near the Ship Shape Community Center, though they also occurred at other locations along the route. Shuttle operators noted that signal losses were more frequent at Ship Shape Community Center. This is discussed further in Section 7.4.

Figure 5-4. Mapping of "Signal Loss" Disengagements

5.1.5 Fault Code/Error Codes

Figure 5-5 illustrates the location of "Fault Code/Error Code" disengagements. As shown, these instances appear in small clusters across the route.

Figure 5-5. Mapping of "Fault Code/Error Code" Disengagements

5.1.6 Other Disengagements

Figure 5-6 illustrates the location of "Priority Zone," "Shuttle Deviated from Approved Path," "Station Blocked," "Vegetation," "Vulnerable Road Users," and "Weather" disengagements, which, together, account for 8% of all shuttle disengagements. Notably, several "Shuttle Deviated from Approved Path" disengagements occurred near the 9th Street at Avenue H stop. After further investigation, it was confirmed that most of these disengagements occurred at the start of service when the vehicle had issues recognizing the stop location. This issue was quickly reviewed and addressed by Beep.

The instances of "Weather" are further discussed in Section 7.3 of this report. Due to the low sample size of the other examples of disengagement occurrences, no further investigation was conducted.

Figure 5-6. Mapping of Other Disengagements

5.2 INCIDENTS

In the first month of operations, two incidents occurred that required shuttles to be pulled from service. The first involved a shuttle striking a curb, which TIMMA reported to CA DMV. The second was a non-injury collision where a passenger vehicle collided with the shuttle at low speeds. This incident was reported to both NHTSA and CA DMV.

5.2.1 P32 Curb Strike

On August 16, shuttle P32 was exiting the YMCA stop station when its right-side wheels traversed the adjacent curb. No injuries were reported. An investigation conducted by Beep revealed that the rear LiDAR devices were mis-calibrated, resulting in the vehicle veering off its planned path due to poor localization. Part of the investigation determined that a metric used to track LiDAR localization quality, also known as "hit ratio" (the ability for the vehicle to geolocate correctly based on existing mapping and imaging obtained from active LiDAR sensors), could be used to evaluate the performance of LiDAR devices. To mitigate this occurrence, Beep implemented a daily pre-service test route loop prior to the start of any vehicle entering operations. The test loop allowed for the hit ratios to be assessed daily to ensure precise localization before the start of service. Average hit ratios above 80% were determined as the threshold for beginning service.

After the LiDAR was recalibrated and testing was complete, shuttle P32 resumed service on September 10. No further issues regarding hit ratios were reported by Beep during the remaining months of operations.

5.2.2 P84 Collision

On August 23, shuttle P84 was involved in a low-speed collision that resulted in minor cosmetic damage to both vehicles. No injuries were reported. The incident occurred at the Seven Seas Avenue and 9th Street intersection. There were no passengers on the shuttle and both vehicles were driven from the scene without assistance. At the time of the incident, the San Francisco Police Department was contacted; however, they declined to respond since the incident resulted in no injuries or significant property damage. The incident was reported to both NHTSA and the CA DMV.

After further investigation, the automated driving system logs showed that shuttle P84 detected and maintained awareness of the other vehicle, which included engaging in a hard breaking maneuver prior to the collision. However, the other vehicle failed to yield to P84 as it continued through the intersection and the on-board attendant of shuttle P84 failed to engage the emergency stop button, which may have allowed the vehicle to have stopped sooner, thereby possibly avoiding the collision. The slight bend in the shuttle's path through the intersection (which was in place to accommodate the lane shift through the intersection), may have reduced the shuttle's available stopping distance. As a mitigation, Beep implemented a "priority zone" — a known area of pedestrian or irregular vehicle activity where sensors are uniquely tuned to detect activity – to account for the bend in the shuttle's path through the intersection. This provided an additional safety buffer in the event future vehicles failed to yield to the shuttle. Additionally, Beep reconfigured all vehicles to drive at slower speeds through the intersection and provided additional training to shuttle operators on the use of the emergency stop button.

After updates were made, the P84 shuttle re-entered testing to return to service. Due to the nature of the incident, Beep conducted 10 consecutive days of testing, including a review and retesting of System Requirements associated with the automated functions of the vehicle, including vehicle braking and maneuverability through the intersection. Once testing was complete, shuttle P84 was reintroduced to the fleet and resumed service on September 27.

6. Outreach

6.1 SURVEY FINDINGS

At the start of operations, TIMMA released a publicly available, multilingual online survey to solicit feedback from Treasure Island residents and visitors. The survey was promoted on the shuttle with a QR code, on the project website, and paper versions were available at Ship Shape Community Center. As shown in the table below, a total of 80 people provided survey responses.

Table 6-1. Survey Responses by Language

SURVEY LANGUAGE	TOTAL RESPONSES
English	57
Chinese	9
Filipino	7
Spanish	7
Total	**80**

Of the 80 responses received, 32 respondents stated that they rode the Loop (referred to as a shuttle "rider"), and 32 stated that they did not ride the Loop (referred to as a "non-rider"). The remaining survey responses were deemed incomplete due to the lack of information provided in their responses.[1] The following sections further evaluate the survey responses of riders and non-riders. Please note that, while demographic information was requested in these surveys, demographic information is omitted in this evaluation due to the limited response rate, making findings unreliable.

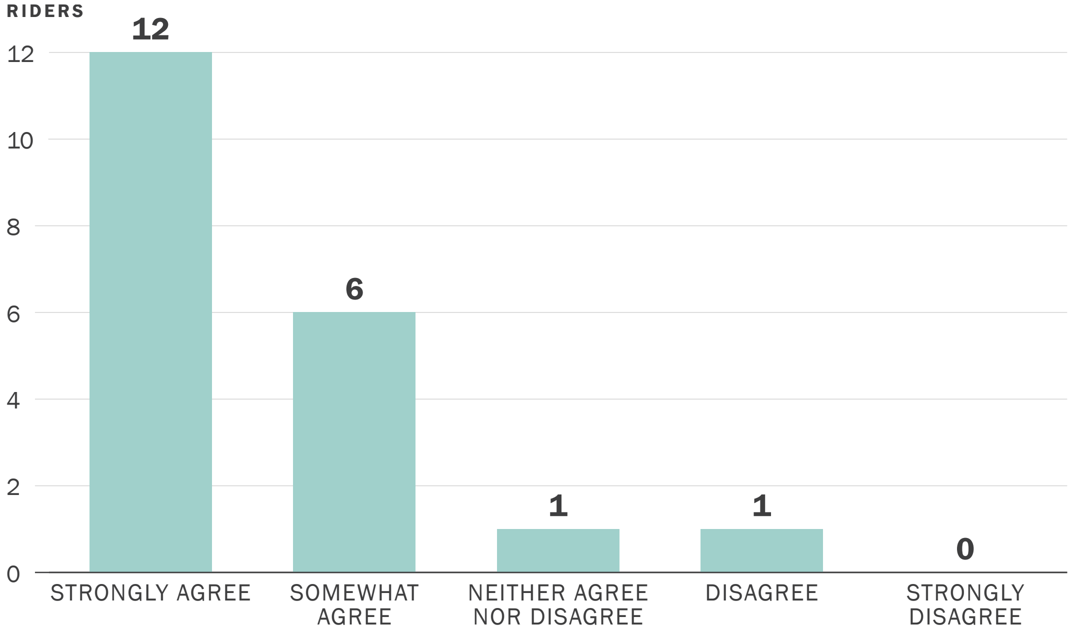
6.1.1 Survey Findings for Riders

Overall Perception

Of the 32 riders who provided survey responses, 20 provided insights into their overall perception of their experience riding the shuttle. Eighteen out of 20 responded they somewhat agreed or strongly agreed that they had a good experience using the shuttle.

1 The majority of survey respondents who did not provide an answer to whether they were a rider or non-rider (the first question of the survey) submitted entirely blank surveys.

Figure 6-1. Surveyed Riders: "I had a good experience using the shuttle"



Safety Perception

Of the 32 riders who provided survey responses, 19 provided insights into their safety perceptions before and after riding the shuttle. Before riding the shuttle, 68% of respondents believed that the shuttles were either somewhat safe or very safe. After riding the shuttle, nearly all respondents believed that the shuttles were either somewhat safe or very safe. These perceptions of safety before and after riding the shuttle indicate an overall positive shift in safety perception after riding the Loop.

Table 6-2. Surveyed Riders: Perception Change After Riding the Shuttle

	BEFORE	AFTER
Very unsafe	0	0
Somewhat unsafe	2	0
Neither safe nor unsafe / no opinion	4	1
Somewhat safe	6	9
Very safe	7	9

Quality of Information

Of the 32 riders who provided survey responses, 19 provided insights on the quality of information they received about the Loop service. As shown in the table below, most respondents acknowledged receiving fair to excellent quality of information regarding the AV shuttle.

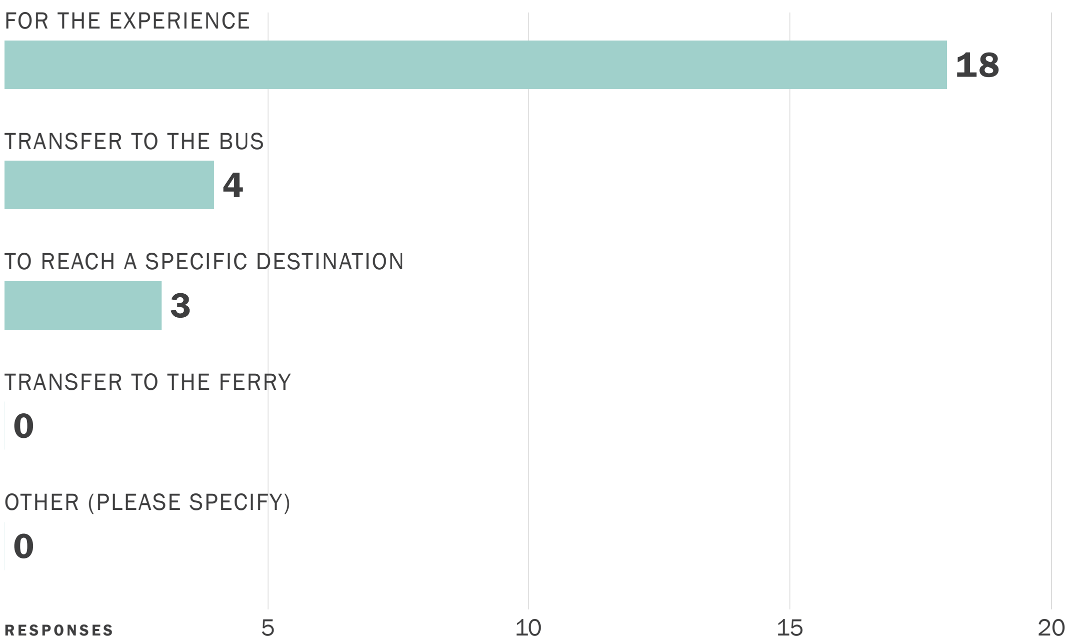
Table 6-3. Surveyed Riders: Quality of Information

	DRIVERLESS VEHICLE TECHNOLOGY	THE PURPOSE OF THE PROJECT	WAYFINDING AND NAVIGATION
Excellent	10	11	7
Good	4	4	7
Fair	4	1	2
Poor	0	3	2
Very Poor	1	0	1

Reason for Shuttle Ride

Of the 32 riders who provided survey responses, 19 provided insights on their reason for riding the shuttle. As shown in the figure below,[1] the majority rode the shuttle for the unique experience it offers.

Figure 6-2. Surveyed Riders: Reason for Shuttle Ride

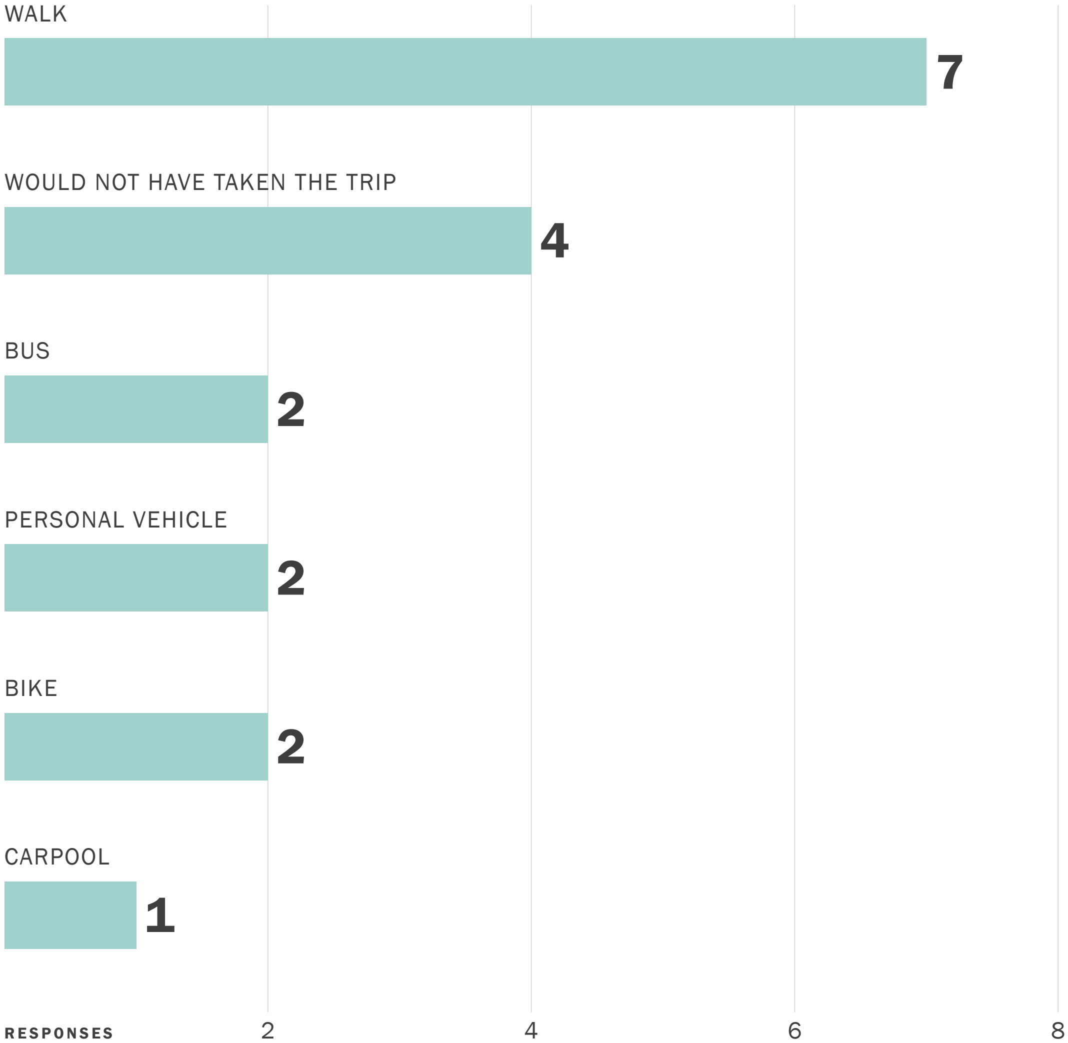


1 Survey respondents were able to record multiple selections. Therefore, total reasons for riding the shuttle may be greater than the total number of survey respondents who responded to this question.

Other Modes of Travel

Of the 32 riders who provided survey responses, 18 provided insights on other modes of travel they would have chosen if they did not take the shuttle. As shown in the figure below, most respondents would have chosen to walk to their destination.

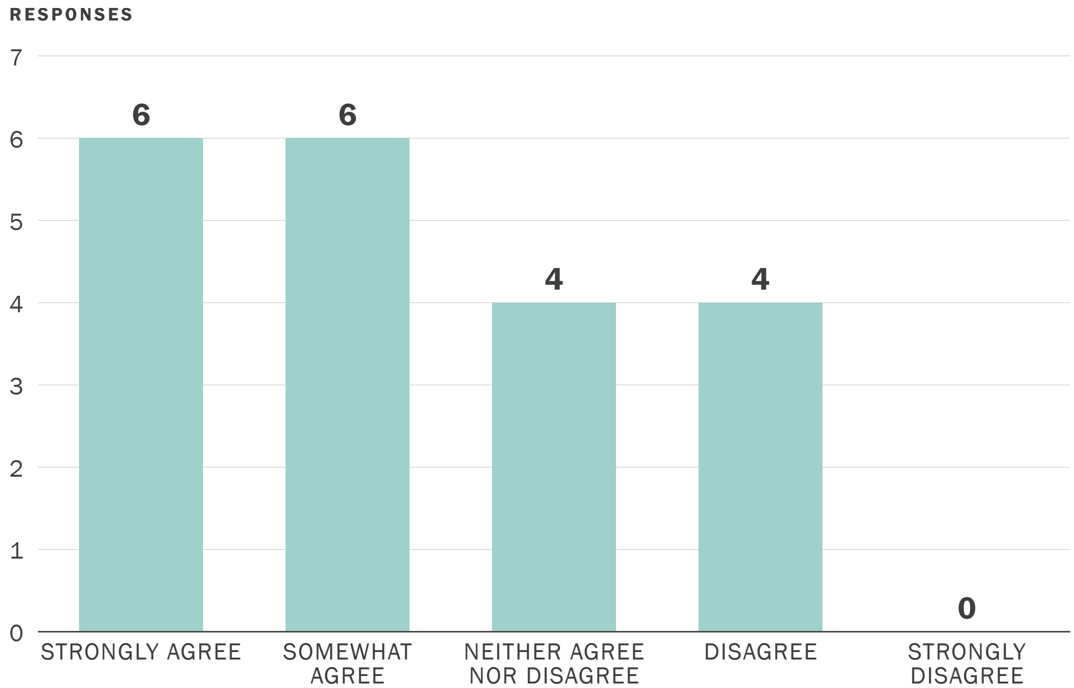
Figure 6-3. Surveyed Riders: Other Modes of Travel



Reliability

Of the 32 riders who provided survey responses, 20 provided insights into their perception of the shuttle's reliability. Twelve of 20 responded that they somewhat agreed or strongly agreed that the shuttle arrived in a reasonable amount of time, indicating mixed perceptions of the shuttle's reliability.

Figure 6-4. Surveyed Riders: "The shuttle arrived at my stop within a reasonable amount of time."



Subsequent Rides

Of the 32 riders who provided survey responses, 19 provided insights on if they would ride again. Of these respondents, 17 expressed their willingness to ride the shuttle again, indicating a positive overall perception and a high likelihood of a future shuttle ride.

6.1.2 Survey Findings for Non-Riders

Safety Perception

Of the 32 non-riders who provided survey responses, nine provided insights into their safety perceptions before and after traveling on the road with the AV shuttles. Before encountering the shuttles, six respondents perceived the shuttles as either safe or very safe. After encountering the shuttles, only one respondent had a negative perception change. This one respondent noted that the shuttle was blocking the road at bus stops and stop signs. The remaining respondents either maintained a neutral stance or perceived the shuttle as safer after traveling near the shuttle.

Table 6-4. Surveyed Non-Riders: Perception Change After Traveling Near the Shuttle

	BEFORE	AFTER
Very unsafe	1	1
Unsafe	0	1
Somewhat unsafe	1	1
Neither safe nor unsafe	1	1
Safe	4	2
Very safe	2	3

Shuttle Predictability

Of the 32 non-riders who provided survey responses, eight provided insights into their perception of the Loop behaving predictably. The majority stated that the shuttle behaved in a predictable manner.

6.2 COMMUNITY OUTREACH

During the planning process, TIMMA conducted outreach to the Treasure Island community to help shape the future Loop service. Through a survey, online townhall, and discussion with local businesses, the project team received input on stop locations, hours of operations, and general concerns and opportunities about an eventual launch of the shuttle service.[1] The project team also organized community partnerships to increase awareness of career paths in the AV industry.

To introduce the shuttle pilot program, TIMMA hosted a virtual town hall on October 25, 2022, to provide the community an opportunity to give feedback and learn about the Loop and the potential route and stops. TIMMA collected feedback through a survey to understand the travel needs of the community. The survey was open from October 2022 to November 2022 and available in English, Spanish, and Chinese. The survey received a total of 58 responses. In addition, TIMMA presented to the SFMTA's Multimodal Accessibility Advisory Committee, One Treasure Island, and Office of Economic Workforce Development to discuss opportunities for partnership and support.

Prior to implementation of the Loop service, TIMMA and Beep held in-person events to give future riders an opportunity to experience the shuttle in person and ask the project team questions. TIMMA hosted a Loop Community Day on July 18, 2023, which was held at the Ship Shape Community Center. This event had two parts. The first was focused on the disability community and representatives from Lighthouse for the Blind and Visually Impaired and SFMTA's Accessible Services Division got a tour of the shuttle and provided accessibility-related feedback for the project team to consider before launch. The second portion of the event corresponded with the Weekly Food Pantry hours and provided the public an opportunity to tour the shuttle and get rider information.

1 Feedback on stop locations emphasized the interest in serving the Treasure Island Sailing Center and Ferry Terminal, which was ultimately no feasible due to roadway construction and permitting.

The project team also attended National Night Out on August 1, 2023, a community event hosted by One Treasure Island, and distributed information about the shuttle to interested residents.

Figure 6-5. The Loop Community Day

TIMMA launched the shuttle pilot on August 13, 2023, with a community event held at Ship Shape Community Center. This event provided the community an opportunity to be one of the first to ride the shuttle and meet with the project team to ask questions.

6.2.1 Community Partnerships

When TIMMA received the ATCMTD grant, the Board expressed the importance of using this pilot project as an opportunity to better understand the impacts of future AV adoption on local labor and workforce. In response, the project team organized community partnership programs to engage with labor groups and SFUSD.

The project team facilitated a workshop on March 5, 2024, for STEM students at Willie Brown Jr. Middle School in San Francisco's Bayview District. Students learned about the shuttle pilot on Treasure Island, completed activities to learn about AV technology, and engaged in a discussion about career pathways in the AV and transportation planning industry.

The project team also facilitated an event on March 15, 2024, for labor unions and students in automotive and engineering courses from City College of San Francisco. The event introduced the shuttle pilot on Treasure Island, workforce opportunities, and key roles needed to support these technologies from maintenance, fleet management, and monitoring and oversight.

Figure 6-6. The Loop STEM Event

7. Lessons Learned

7.1 PROCURING SHARED AV SHUTTLES PRESENTS A NEW SET OF CHALLENGES

Currently, there are a limited number of operators and manufacturers that offer a shared AV solution for public transportation. This ultimately limits the competitiveness of the procurement process and presents challenges during selection and contracting. During TIMMA's procurement of the AV shuttle, the shared AV solutions that were proposed were all unique and therefore not easily comparable in terms of qualifications and references. Furthermore, the Loop's route was entirely on public right of way, which differed from other deployments across the U.S. In addition to these concerns, TIMMA was also made aware of the limited number of AVs that are readily available for use industry wide. During the selection process, it was important to ensure that prospective vendors could deliver, test, and commission vehicles in a timeline that did not conflict with other pilots across the U.S.

In addition to the limited number of AV shuttles that are readily available, there is also a limited selection of AV shuttle types offered by industry manufacturers. In comparison to traditional buses, most shared AVs are small and have a capacity for 10 or fewer passengers. Additionally, capacity is further constrained with the introduction of wheelchair passengers and other mobility devices brought on board by commuters. Furthermore, while shared AVs are equipped with ADA ramps to assist with boarding and alighting passengers, they often require manual deployment from on-board AV shuttle attendants.

7.2 INCIDENT RESPONSE AND COMMUNICATIONS CAN REQUIRE SIGNIFICANT RESOURCES

As described in Section 5.2, TIMMA worked closely with Beep to return vehicles to service after the curb strike and non-injury collision incidents. Following both incidents, Beep pulled the AV shuttles from service until they could be retested and approved by TIMMA to re-enter service.

After coordinating with regulators to confirm their permission to resume operations, TIMMA had to develop a formal protocol for returning vehicles back to service. After discussion with the project team, TIMMA initiated the development of a standard operating procedure to provide formal guidance if future incidents occurred. This created a unified approach to returning vehicles to service, highlighted the retesting of various System Requirements, and provided a recommendation for the number of testing days required. As shown in Section Table 7-1, the recommended number of testing days was tiered based on the response of the AV shuttle's automated driving system during the incident, and the incident impact to the vehicle and its passengers.

With regular service disruptions, Beep and TIMMA staff worked collaboratively to establish procedures and protocols to provide public notices quickly and efficiently. Communications were distributed via the Loop rider website, hand placed signs at each of the stop locations, and on the Loop social media accounts. This ultimately required significant TIMMA staff resources as service disruptions occurred throughout the pilot for various reasons.

Table 7-1. Return to Service Testing Recommendations

ADS RESPONSE:	INCIDENT OUTCOME: NO REPORTED DAMAGES OR INJURIES	PROPERTY DAMAGE ONLY	INJURY REPORTED
ADS Operated As Expected; No Mitigation Measures Needed	1 Consecutive Day of Successful Testing	2 Consecutive Days of Successful Testing	N/A — Pilot Suspended
ADS Operated As Expected; Mitigation Measures Put in Place	2 Consecutive Days of Successful Testing	4 Consecutive Days of Successful Testing	N/A — Pilot Suspended
ADS Did Not Operate As Expected; Mitigation Measures Put in Place	4 Consecutive Days of Successful Testing	7 Consecutive Days of Successful Testing	N/A — Pilot Suspended

7.3 TECHNOLOGY CAN BE UNRELIABLE

As a critical component of the AV, the shuttles are outfitted with two 360-degree field of view LiDAR sensors and six 180-degree field of view LiDAR sensors. Together, these sensors provided the automated driving system critical information to conduct autonomous operations. During operations, all three shuttles experienced issues with their LiDAR devices, resulting in extended outages of one or more shuttles. These issues led to an increased need to coordinate with GMM (the AV vehicle manufacturer) to support as needed LiDAR recalibrations based on testing and technical reviews completed by Beep. Ultimately, shuttle P66 required a replacement LiDAR device and calibration delaying its initial startup. P32 also required a LiDAR recalibration after the existing rear LiDAR device was found to be mis-calibrated, which resulted in the curb strike incident discussed in Section 5.2. The coordination required between Beep and GMM included several days of communication, recalibration, and testing, which ultimately prolonged the time for the vehicles to return to service.

Additionally, in late October, shuttle P84 was removed from service due to LiDAR damage from local rainstorms. While it is known that LiDAR technology is sensitive to rain, water and puddling on roads, the team did not anticipate that rain would damage the LiDAR device itself. Like the prior instances, a full LiDAR replacement was required, which required further coordination with GMM to recalibrate the new sensors upon arrival. Overall, this LiDAR replacement and recalibration took nearly one month to complete.

"Signal Loss" is defined as a loss of signal to 5G (cellular communications protocol), global navigation satellite system (GNSS), or real-time kinematic positioning (RTK) communication links. Each of these are communication media utilized by an AV shuttle to receive and transmit global positioning data, which is then used to navigate the route autonomously. As discussed in Section 5.1, many shuttle disengagements were attributed to instances of "Signal Loss." In the case of signal loss, the shuttle attendant is required to navigate the shuttle in manual mode until the signal is strengthened enough to reengage autonomous mode. Early in the project, signal loss was identified as a potential issue due to several instances occurring during initial vehicle testing. To mitigate these concerns, Beep procured a second cellular service provider to improve signal connectivity between the satellite downlink terminal located at Beep's Treasure Island garage and the AV. While this did improve overall signal connectivity, ongoing signal connection issues still occurred at the Ship Shape Community Center. In most instances, signal connectivity was regained after a brief period of downtime ranging from 1 to 3 minutes. However, some instances of downtime were longer and required a hard reset of the vehicle. Ultimately, these signal loss events contributed to a poorer service quality for passengers.

7.4 COMPLEX OPERATING ENVIRONMENT INCLUDING ACTIVE CONSTRUCTION PRESENTS RISKS TO PILOT DELIVERY

As discussed in Section 5.1, most shuttle disengagements were attributed to instances of "Other Road Users" and "Obstacle Detection." Together, these instances accounted for 72% of all shuttle disengagements. As noted previously, Treasure Island is undergoing a significant redevelopment and infrastructure transformation. This resulted in a variety of ongoing changes to the surrounding environment, including the presence of construction crews, nearby road closures, on-street parking, and an increased presence of emergency vehicles at the local fire station. As they are currently designed, many AV shuttles operate on a fixed track and are supported by geofenced mapping. As such, manual intervention may be required to deviate from any unplanned obstacles. Furthermore, the Loop ceased operations after four months due to road configuration changes that impacted the AV shuttle's ability to navigate the route as expected.

7.5 INNOVATIVE DEPLOYMENTS REQUIRE UNIQUE STAFFING AND RESOURCING

Early on, TIMMA identified the need to provide specialized staff support for this project. In doing so, TIMMA staff managed the project with the assistance of consultants at HNTB. Even with this support, the agency did not anticipate the level of involvement that would be required throughout the planning, procurement, permitting, testing, and operational phases of the project, which ultimately exceeded initial staffing estimates.

Furthermore, during the operational phase of the project, the project team dealt with several issues around ample staffing for on-board shuttle operators. As described earlier in the report, service disruptions occurred due to shuttle operator absences and breaks. Additional redundancy in shuttle operator staffing could have proved beneficial to the project.

7.6 DEMAND EXISTS FOR FIRST AND LAST MILE SOLUTIONS

Overall, the project showed in many ways that the demand for first and last mile solutions exists. Throughout the project, the local community was actively engaged and interested in learning more about a new way to travel around the Island. Additionally, the community largely shared that they had a positive experience with the AV service. However, the pilot demonstration also showed that shared AV technology still requires improvements to become a more reliable and convenient mode of travel.

7.7 CONTRACTING FOR RISK MANAGEMENT

This pilot utilized a milestone based contract that set target levels for service to be delivered as well as requirements for data reporting, testing, training, etc. It did not anticipate the level of missed service or equipment repairs which required a significant amount of project management and negotiation by both TIMMA and Beep. In order to ensure efficient coordination and manage operational risk, the operating agreement should be specific about the details of service delivery (e.g., number of vehicles dedicated to the project) and compensation or consequences for meeting or not meeting the targets for service.

7.8 BUSINESS CASE ANALYSIS

The USDOT grant obtained by TIMMA requires a brief business case analysis comparing AV shuttle service with traditional public transit (Muni) provision of future transit service on Treasure Island. Appendix C compares the performance, costs, and risks associated with operating an AV shuttle versus traditional bus service.

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TREASURE ISLAND MOBILITY MANAGEMENT AGENCY

THE LOOP FINAL EVALUATION REPORT
APPENDIX A

Evaluation Methodology

Evaluation Methodology

The Final Evaluation Report includes an analysis of several performance metrics. The following table provides a brief explanation of the methodology utilized to determine each, including the source of the data utilized. Furthermore, the following reporting timeframes are referenced throughout this report:

- Month 1: August 16th, 2023 – September 15th, 2023
- Month 2: September 16th, 2023 – October 15th, 2023
- Month 3: October 16th, 2023 – November 15th, 2023
- Month 4: November 16th, 2023 – December 10th, 2023

Metric	Methodology	Data Source
Incidents	A total of all incidents, which include collisions, near misses, or other notable events that impact the safety of passengers.	Weekly Incident Report
Disengagements	A total of all disengagements (occurrences when the shuttles require manual operation). Data is summarized by disengagement cause. Instances occurring during testing, during non-operational times, or off the shuttle route are excluded.	Weekly Disengagement Report
Ridership	A total of all passengers that boarded the AV shuttles.	Weekly Ridership Report
ADA Ramp Deployments	A total of all instances in which an ADA ramp is deployed for a shuttle passenger.	Weekly Report
Wheelchair Securements	A total of all instances when a shuttle attendant secures a wheelchair passenger.	Weekly Report
Service Miles Traveled	A total of miles traveled by each shuttle operating on the route.	Monthly Vehicle Data
Service Hours Traveled	A total of hours traveled by each shuttle operating on the route.	Monthly Vehicle Data
Service Uptime %	Calculated in three ways: 1) By taking the Total Recorded Completed (# of service loops run), divided by Expected Runs Completed, which is calculated at 22 per day based on the 27-minute headway requirement in Beep's contract, which equates to 9 runs between 9am and 1pm (1 shuttle only), 4 runs between 1pm and 2pm (2 shuttles), and 9 runs between 2pm and 6pm (1 shuttle only). 2) By taking the Total Miles Traveled in a month, divided by Expected Miles Traveled, which is calculated at 33 miles per day based on an assumed 22 runs completed each day at 1.5 miles each. 3) By taking the Total Hours Traveled in a month, divided by Expected Hours Traveled. Expected Hours Traveled is derived by multiplying 10 hours (9 hours for 9AM-6PM service + 1 hour overlap of two shuttles operating midday) by the number of days in each month. Exceptions are granted based on agency directed service closures (i.e., planned events). Additionally, a summary of service interruptions is provided by Beep for further comparison and analysis.	Weekly Report; Monthly Availability Tracker

Metric	Methodology	Data Source
Average Battery Depletion	The difference between the starting and ending battery life of a shuttle by shift or by loop.	Weekly Report
Average Headways	The average time interval between shuttles arriving at a stop location. Data stamps are provided for arrivals at each stop location. The time stamp is converted to Pacific Standard Time and compared between loops to calculate an estimated headway time. Immediate stops (reopening of passenger doors), stops completed before 9AM (start of service), and known service disruptions that caused significant time delays (80 minutes or more) between loops are removed from this calculation.	Monthly Vehicle Data
Average Dwell Time	An average of the amount of time a vehicle is stopped at stop locations along the route. Data is converted to minutes. 0-second dwell times (shuttle didn't stop, or records at the start of a run) and outliers (95-th percentile) are removed from this calculation.	Monthly Vehicle Data
Average Shuttle Speeds	Average speed of the shuttle, excluding all scheduled stops. Data is provided as a daily average and is aggregated by month.	Monthly Vehicle Data

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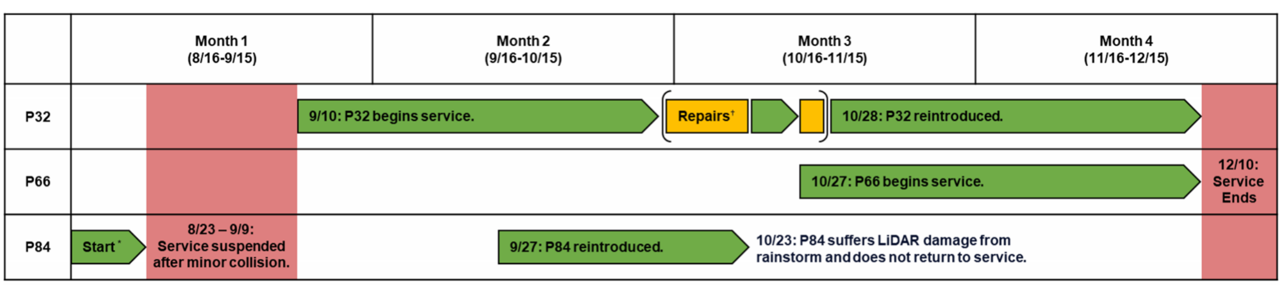
Service Disruptions

Service Disruptions

During the 4 months of operations, there were operational challenges that caused multiple service disruptions. This included a temporary shutdown of service and, later, the early termination of the pilot. Initially, the project intended to have two AV shuttles available to each provide 5 hours of service every day, with one hour of overlap. Due to these ongoing challenges, a third shuttle was provided by Beep to support service continuity. The three shuttles are referred to below by the shorthand names given by the manufacturer: shuttles P32, P66, and P84.

The following bullets are a chronological summary of the challenges that occurred during operations. This is followed by an illustration of these issues on a timeline. The impacts of these service disruptions are discussed further in the Final Evaluation Report.

- Prior to the start of service, P66 was not ready for operational service due to issues with the vehicle's LiDAR equipment.
- August 16, 2023: P32 was removed from service after hitting a curb. Passenger service began with P84 only.
- August 23, 2023: P84 was removed from service after a low-speed non-injury collision. Service was temporarily suspended.
- September 10, 2023: Service resumed after safety enhancements were made to the shuttle route. Service resumed with P32 only.
- September 27, 2023: After successful testing, P84 resumed service. This marked the first time two shuttles, P32 and P84, operated simultaneously.
- October 14, 2023: P32 was removed from service to repair a faulty cable.
- October 23, 2023: P32 returned to service. P84 was removed from service due to LiDAR damage from local rainstorms.
- October 27, 2023: P32 was removed from service to repair a faulty mounting bracket. After successful testing, P66 entered service.
- October 28, 2023: P32 returned to service. From this point forward, shuttles P32 and P66 were operating on the route simultaneously.
- December 10, 2023: Service suspended due to roadway changes.
- January 1, 2024: TIMMA announced the early conclusion to Loop service due to changes in road conditions.



* 8/16: Service begins with P84 only. P32 does not begin service due to curb strike. P66 remains in testing due to LiDAR issues.

† 10/14-10/28: P32 undergoes repairs, is briefly returned to service, and undergoes further repairs until being reintroduced to service once again.

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APPENDIX C

Business Case Analysis

Business Case Analysis

The following sections compare the performance, costs, and risks associated with operating an AV shuttle versus traditional bus service. Data retrieved from SFMTA's 25-Treausre Island bus line (the "25") is compared to data retrieved from the Loop operations. While this section intends to compare the 25 and the Loop, the 25 provides service to downtown San Francisco, which the Loop did not. In addition, on Treasure Island proper, the 25 covers approximately 3.5 miles with 15 passenger stops, whereas the Loop covered approximately 1.5 miles with 7 passenger stops. The 25 overlaps with the Loop's route through the residential district of Treasure Island, while also providing service to an eastern portion of Treasure Island, the Treasure Island Museum and Ferry Terminal, and ultimately downtown San Francisco. See below for the route map of the 25 Treasure Island.

Performance

Ridership

As shown in the table below, in calendar year 2023, the Muni-25 line averaged approximately 1,100 daily passenger boardings on weekdays. In comparison, the Loop averaged approximately 12 daily passenger boardings on weekdays. This difference is largely influenced by the 25 route's connection to downtown and to additional parts of Treasure Island. Currently, the 25 is the primary public transportation option between Treasure Island and downtown San Francisco as it is connected to the Salesforce Transit Center and other local and regional transit options. In contrast, the Loop was primarily used as a local route for short, interconnected trips within Treasure Island.

Service Hours

In calendar year 2023, the 25 anticipated providing 22,281 service hours to passengers. In total, 22,250 service hours were delivered. This represents approximately 99.9% of scheduled service hours that were delivered in 2023. In comparison, at the conclusion of operations, the Loop provided approximately 91% of its planned service hours. This difference is largely attributed to the size and efficiency of SFMTA's bus fleet. SFMTA is operationally prepared to support unanticipated operator absences, regular vehicle maintenance, and vehicle testing/repairs with minimal impacts to service. In addition to the non-injury collision that suspended service, the Loop was significantly impacted by downtime associated with these types of unanticipated issues.

Headways

Currently, the 25 has a goal headway of approximately 20 minutes on weekdays, and 25 minutes on weekends. The Loop had a headway goal of approximately 27 minutes during all operational hours. Although the 25 covers significantly more miles and includes twice the number of stops, the 25 is still capable of providing more frequent service for passengers than the Loop. This is largely attributed to the vehicle fleet available to SFMTA. During weekday operations, SFMTA operates 2-3 buses simultaneously on the 25. Conversely, the Loop operated a single AV shuttle for most of the day. Furthermore, SFMTA buses typically travel at a higher average speed of around 8 MPH, whereas the Loop traveled closer to 4-5 MPH on its route, which contributed to a slower pace and ultimately a longer headway.

	SFMTA 25 Treasure Island	**The Loop**
Average Daily Weekday Boardings	1,100 (1)	12 (2)
Scheduled Service Hours Delivered	99.9% (1)	91% (2)
Expected Weekday Headways	20 minutes (3)	27 minutes (3)
Average Travel Speeds	8 MPH (4)	4-5 MPH (2)

(1) Based on calendar year 2023 data retrieved from SFMTA.
(2) Based on the Loop's 4 months of operational data.
(3) Actual headways for the 25-Treasure Island were not provided, therefore expected headways are shown.
(4) Based on average speeds of SFMTA's entire bus fleet.

Cost

To compare the cost difference between operating the Loop and traditional bus service, the following metrics were compared:

- Operating Expense Per Vehicle Revenue Mile (OE per VRM): The expenses required to operate passenger service per revenue mile traveled providing passenger service. Since the Loop was free, total miles traveled while providing passenger service is utilized.
- Operating Expense Per Vehicle Revenue Hour (OE per VRH): The expenses required to operate passenger service per revenue hour traveled providing passenger service. Since the Loop was free, total hours traveled while providing passenger service is utilized.

Based on 2022 data provided in the Federal Transit Administration's (FTA) National Transit Database (NTD), SFMTA's OE per VRM and OE per VRH for bus service was approximately $33.63 and $265.10, respectively. As shown below, based on data gathered during 4 months of operations, the Loop's OE per VRM and OE per VRH was approximately $88.66 and $254.62, respectively.[1] Also shown below are the total operating expenses, revenue miles, and revenue hours used to calculate the metrics noted above.

	SFMTA Bus Service	**The Loop**
Operating Expense Per Vehicle Revenue Mile (OE per VRM)	$33.63	$88.66
Operating Expense Per Vehicle Revenue Hour (OE per VRH)	$265.10	$254.57
Operating Expense	$412,244,509 (1)	$267,296 (2)
Total Revenue Miles	12,259,450 (1)	3,015 (3)
Total Revenue Hours	1,555,039 (1)	1,050 (3)

(1) Based on calendar year 2022 data retrieved from the National Transit Database (NTD) for SFMTA's entire bus fleet.
(2) Based on Beep's total cost for operating 2 vehicles during 4 months of operations. Does not include capital costs, staff costs, or other costs incurred by TIMMA to support on-going operations.
(3) Based on the Loop's 4 months of operational data.

Generally, the OE per VRH for both services is similar. However, when comparing the OE per VRM, which considers total miles traveled while providing passenger service, the AV shuttle appears to be a more costly alternative. This is expected when considering how both vehicles operate. Based on the evaluation findings presented earlier, during a comparable time span, a bus is likely to cover significantly more miles at a higher travel speed and with greater reliability than an AV shuttle.

[1] Operating expenses are defined by NTD as all expenses associated with the operation of the transit agency and are classified by the FTA's Uniform System of Accounts (USOA). The operating expenses used for the Loop are solely based on the project contract for Beep to operate 2 vehicles during 4 months of operations and does not include capital costs, staff costs, or other costs incurred by TIMMA to support on-going operations.

Risks

Procurement

Currently, there are a limited number of operators and manufacturers that offer a shared AV solution for public transportation. This ultimately limits the competitiveness of the procurement process and presents challenges during selection and contracting. During TIMMA's procurement of the AV shuttle, the shared AV solutions that were proposed were all unique and therefore not easily comparable in terms of qualifications and references. Furthermore, the Loop's route was entirely on public right of way, which differed from other deployments across the US. In addition to these concerns, TIMMA was also made aware of the limited number of AVs that are readily available for use industry wide. During the selection process, it was important to ensure that prospective vendors could deliver, test, and commission vehicles in a timeline that did not conflict with other pilots across the US.

Conversely, the market for procuring buses and contracting with bus operations vendors is far more competitive and mature. Furthermore, SFMTA already provides bus service on Treasure Island. As planned in the Treasure Island Transportation Program, TIMMA has plans to provide intra-Island shuttle services and these are not anticipated to be autonomous. Vehicle Specifications

In addition to the limited number of AV shuttles that are readily available, there is also a limited selection of AV shuttle types offered by industry manufacturers. In comparison to traditional buses, most shared AVs are small and have a capacity for 10 or fewer passengers. Additionally, capacity is further constrained with the introduction of wheelchair passengers and other mobility devices brought on board by commuters. Furthermore, while shared AVs are equipped with ADA ramps to assist with boarding and alighting passengers, they often require manual deployment from on-board AV shuttle attendants.

Operational Rigidity

The Loop ceased operations after 4 months because of road configuration changes that impacted the AV shuttle's ability to navigate the route as expected. Because the operating environment for the AV is shaped by mapping and testing activities prior to the start of service, evolving external conditions have the potential to be highly disruptive. This ultimately creates a rigid operating environment as compared to that of a traditional bus service, which is more easily modified to support ongoing construction, road closures, planned special events, and other unanticipated activities.

Furthermore, Beep AVs are highly sensitive to inclement weather, such as rain, wind, and other low visibility environmental conditions. As demonstrated in the pilot, rain, which is common in the San Francisco Bay Area, caused damage to the AV shuttle's LiDAR system and impacted service for several days. Similarly, poor pavement conditions may have led to issues with sensor calibration, though this is speculation and was not proven to be true.

Staffing

TIMMA staff managed the project with the assistance of consultants HNTB. Even with this support, the agency did not anticipate the level of involvement that would be required throughout the planning, procurement, permitting, testing, and operational phases of the project, which ultimately exceeded initial staffing estimates.

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APPENDIX D

SOP for Returning Vehicles to Service

Treasure Island AV Shuttle Pilot Project

To:	Aliza Paz (SFCTA)
From:	Esteban Martinez (HNTB), Rich Shinn (HNTB)
Date:	10/5/2023
Subject:	SOP: Returning Vehicles to Service

TIMMA is currently in the operational phase of the Treasure Island Autonomous Vehicle (AV) Shuttle Pilot Project. To date, several incidents have caused TIMMA to evaluate the need for a Standard Operating Procedure (SOP) that outlines steps for returning AV shuttles back into service. The following procedures provide such guidance.

Step 1: Incident Report (Root Cause Analysis)

The contract terms specify that in the event of an incident a report shall be provided to TIMMA within 48 hours. Beep refers to this document as a Root Cause Analysis Report. The Incident Report includes a written summary of the incident[1] that caused the vehicle to be pulled out of service, providing context on the nature of the incident, the ADS or other vehicle software/hardware role, key elements (including but not limited to the involvement of passengers, first responders, the on-board operator, and/or news media), and any data or information regarding the expected operations or malfunctions of the vehicle's hardware/software. These findings should be summarized in a way that clearly identifies the root cause of the incident. The Incident Report and accompanying information shall be documented via email or a brief memorandum to TIMMA.

Upon receipt, TIMMA staff will review it to determine if the root cause identified by the vendor is agreed upon. If additional data or information is required to complete this evaluation, TIMMA will provide written comments or clarifications for Beep to respond to in writing, which will serve as an attachment to the report. The vendor shall provide any additional data or information at the request of TIMMA.

Step 2: Recommended Changes

After determining the root cause, the vendor shall identify any changes that are required to fix the vehicle (e.g., hardware components, software upgrades, etc.) prior to performing maintenance/updates. In addition, the vendor shall identify if other vehicles in TIMMA's fleet require similar changes to mitigate potential issues in the future. Any recommended changes to vehicles in TIMMA's fleet shall be clearly communicated and documented via email or a

[1] If the incident resulted in a collision, the vendor is required to report the incident to NHTSA based on NHTSA's guidance on collision reporting: https://www.nhtsa.gov/laws-regulations/standing-general-order-crash-reporting.

brief memorandum to TIMMA. Upon receipt, TIMMA will review the recommended changes and be provided with an opportunity to seek clarification or further information to determine no objection to the proposed changes. If additional information is required, the vendor shall provide it at the request of TIMMA.

Thereafter, the vendor shall provide a Root Cause Test Plan outlining an approach to testing the specific functions of the vehicle that demonstrate the vehicle's ability to mitigate or resolve the root cause issue. It shall also identify where (either on-route during off hours or at the maintenance facility), duration (number of days), and when (time of day and expected testing hours) the vehicle will require testing. This plan shall be documented via email or a brief memorandum to TIMMA. Upon receipt of the Root Cause Test Plan, TIMMA will review the vendor's proposed approach. Once the approach is agreed upon, TIMMA will provide approval for the vendor to proceed with an initial trial of the tests as outlined in the plan.

Step 3: Initial Testing

The initial testing is intended for Beep to test the implementation of changes, prior to being in a formal test environment. This provides Beep with an opportunity to verify the effectiveness of the changes. Initial testing shall only be conducted during off hours or at limited locations where there is little public use of the road. This testing will be conducted by the vendor without oversight from TIMMA to allow the vendor to troubleshoot, re-test, identify and resolve on-going issues with the shuttle. All tests will be documented and provided to TIMMA.

Step 4: Formal Testing

Prior to returning the shuttle to operations, formal testing will occur to allow TIMMA to witness both root cause testing as well as standard operational test cases outlined in the approved Test Plan for the project.

Root Cause Testing: The vendor will stage a formal testing meeting to allow TIMMA to oversee the vehicle's ability to meet the test criteria outlined in the Root Cause Test Plan. If the vehicle does not pass these tests, the vendor shall reassess and re-schedule testing for a future date. If modifications are required to the Root Cause Test Plan, the vendor shall communicate these to TIMMA for approval.

Operational Testing: The vendor will also be required to rerun several test cases outlined in the project's initial Test Plan to ensure operational readiness. These include:

- Test Case 10: Brake Assist (audible alert and hard brake)
- Test Case 12: Shuttle Detects Object (indicating on display and reacts appropriately)
- Test Case 17: Confirm Speed Limit
- Test Case 18: Detect Stop Signs and Pedestrian Crossings
- Test Case 19: Decrease Speed and Pull Over at Programed Locations
- Test Case 24: Pull Over to Side of Road
- Test Case 25: Navigate Unsignalized Intersection

- Test Case 28: Switch from Autonomous to Manual Mode (operator)
- Test Case 29: Right of Way Decision at Intersection: Stop and Go Command

The preferred method for validating these test cases will be along the shuttle route to ensure the vehicle is prepared for operations. Based on the nature of the incident, TIMMA may request additional test cases to be rerun. If so, TIMMA will communicate these to the shuttle vendor in advance of the formal testing meeting.

On Route Testing: Additionally, on-route testing will take place to replicate an environment where service is being provided and to verify that there are no outstanding issues. The following table shall be utilized to determine the appropriate amount of time for on route testing.

Incident Outcome: / ADS Response:	No Reported Damages or Injuries	Property Damage Only	Injury Reported
ADS Operated As Expected; No Mitigation Measures Needed	1 Consecutive Day of Successful Testing	2 Consecutive Days of Successful Testing	N/A – Pilot Suspended
ADS Operated As Expected; Mitigation Measures Put in Place	2 Consecutive Days of Successful Testing	4 Consecutive Days of Successful Testing	N/A – Pilot Suspended
ADS Did Not Operate As Expected; Mitigation Measures Put in Place	4 Consecutive Days of Successful Testing	7 Consecutive Days of Successful Testing	N/A – Pilot Suspended

Step 5: Returning to Operations

Upon completion of formal testing, TIMMA will inform the vendor that the vehicle is approved for operations. At this time, TIMMA and the vendor will agree upon a scheduled date to return the vehicle to operations.

For the first week of operations, daily updates will be provided. If issues are reported or updates are not provided, TIMMA will request daily data reporting in a format that is consistent with the weekly report provided by BEEP. TIMMA will assess this data to ensure there are no abnormalities in the vehicle's ability to navigate the route, which is likely to include a close evaluation of AV disengagements, near misses, and incidents. If a disengagement, near miss, or incident is linked to the prior identified root cause, or presents an imminent safety concern for passengers, the vehicle will be pulled from service. If no issues arise after the first week of operations, the vehicle will no longer require daily updates and can be included in weekly reporting only.

On-Going Operational Concerns

If on-going issues continue, TIMMA shall consider the following:

Mechanical Issues Impacting the Shuttle's Ability to Serve Passengers: Shuttles may experience mechanical issues throughout the pilot, including issues with tires, door hinges, AC functionality, sign displays, etc. These issues shall be evaluated on a case-by-case basis and communicated to TIMMA as repairs are made to the vehicle. The vendor will be responsible for incorporating these repairs and bringing vehicles back into service in a timely manner. Oversight from TIMMA is not anticipated for these types of repairs.

System Issues Impacting the Shuttle's Ability to Operate Autonomously: If an AV shuttle experiences more than two (2) system issues in a thirty-day period which illustrate the shuttle's inability to operate autonomously, the vehicle shall be decommissioned and undergo a full diagnostic review. The review shall focus on the evaluating the health and service life of the vehicle's sensors/detection equipment, an assessment of the shuttle's ability to geo-locate accurately and consistently, as well as a review of the vehicle's ability to incorporate software configuration changes. The vendor shall coordinate with the vehicle manufacturer as necessary to provide TIMMA with the results of this diagnostic review. Upon review, if TIMMA is not satisfied with the results, the shuttle shall be pulled from service indefinitely.

Incidents Requiring Further Operator Training: If any AV shuttle experiences an incident that is proven avoidable via operator intervention, the vendor shall conduct a training refresh with all shuttle attendants. Specific guidance shall be provided to shuttle attendants regarding how to mitigate similar incidents of this type. TIMMA staff shall be invited to review the training materials and attend the training session, if requested.

Collisions Resulting in Injuries to Passengers: If any AV shuttle experiences a collision that results in injuries to passengers, either minor or severe, all AV shuttles shall be pulled from service and the pilot will conclude. Thereafter, TIMMA will coordinate with the vendor and NHTSA to identify the appropriate next steps for reporting and documentation of the incident.

Significant Operational Downtime: If, in any given month, the vendor fails to attain a minimum of 50% operational time for passenger service, TIMMA shall meet internally to determine the validity of continuing the pilot project. This evaluation shall include discussions with key project stakeholders, including the vendor, MTC, SFMTA, and FHWA.

THE LOOP FINAL EVALUATION REPORT
APPENDIX E

TIMMA AV Concept of Operations

CONCEPT OF OPERATIONS

TIMMA Autonomous Vehicle Shuttle Pilot Project

FINAL CONCEPT OF OPERATIONS

May 2020

PREPARED FOR

San Francisco County Transportation Authority
1455 Market Street
San Francisco, CA 94103

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San Francisco County Transportation Authority

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Acronyms and Abbreviations

APC … Automated Passenger Counter

AV … Autonomous Vehicle

AVS … Autonomous Vehicle Shuttle

ConOps … Concept of Operations

FMLM … First-Mile/Last-Mile

SFCTA … San Francisco County Transportation Authority

SFMTA … San Francisco Municipal Transportation Agency

TICD … Treasure Island Community Development

TIDA … Treasure Island Development Authority

TIMMA … Treasure Island Mobility Management Agency

TITIP … Treasure Island Transportation Implementation Plan

TI/YBI … Treasure Island and Yerba Buena Island

1 Scope

1.1 General

This Concept of Operations (ConOps) serves as the first in a series of engineering documents intended to describe the development of the Treasure Island Mobility Management Agency (TIMMA) Autonomous Vehicle Shuttle (AVS) Pilot Project.

1.2 Document Overview

The purpose of the ConOps is to clearly convey a high-level view of the required AVS system from the viewpoint of each stakeholder. This document frames the overall system and establishes the technical course for the Project by serving as a bridge between early project motivations and the eventual technical requirements. By design, the ConOps is technology independent, focusing on the overall functionality of the proposed AVS system.

The ConOps also serves to communicate user needs for, and expectations of, the proposed system. The document provides stakeholders the opportunity to offer input regarding proposed system functionality and is intended to help form a consensus among stakeholders to create a single vision for the system moving forward.

The intent of the pilot project is to procure and test an AV service, not to develop original technology or equipment. The ConOps is intended to provide a quick reference for project stakeholders to ensure a consistent understanding of project needs, process framework, and other system attributes and to inform procurement documents. It is also intended to be specific in establishing the operational expectations yet allow flexibility in the actual deployment scenario since it is anticipated that construction and maintenance of traffic conditions on Treasure Island and Yerba Buena Island (TI/YBI) during the pilot phase may require dynamic path rerouting.

The document contains the following sections:

- Section 1 provides a document overview.
- Section 2 identifies all documents referenced.
- Section 3 describes the current and supporting systems and the challenge(s) to be addressed.
- Section 4 describes the features that motivate the project's development.
- Section 5 describes the proposed system at a high-level, indicating the operational features that are to be provided, without specifying design details.
- Section 6 describes the Use Cases and Operational Scenarios, which illustrate how the project will operate from various perspectives.
- Section 7 describes the impacts the project will have on multiple stakeholders including system users, owners and operators.
- Section 8 provides an analysis of the impacts presented in Section 7.

1.3 System Overview

The TIMMA AV Shuttle Pilot Project aims to evaluate the potential of autonomous vehicle (AV) technology to improve first-mile/last-mile (FMLM) and intra-island mobility on TI/YBI, as described in the Treasure Island Transportation Implementation Plan (TITIP). The TITIP prioritizes pedestrian and bicycle mobility, enhanced by shared mobility services in order to minimize the need for travel in a personal vehicle. To design the streets in a way that prioritizes pedestrian and bicycle mobility, in the final future condition of the island, the intra-island bus service will be replaced with shuttles on the island, with high-capacity bus and ferry service at a central Transit Hub.

The shuttle system envisioned by the TITIP is a shared shuttle operated by a human driver. An AVS system could better fulfill the mobility needs on TI/YBI. AVSs have the potential to reduce operating costs and attract residents and visitors to the islands and the city. Most AVS currently on the market are electric, with no tailpipe emissions, which supports the TITIP's sustainability goal of an environmentally-sensitive means of transportation. The pilot project will allow the TIMMA and its stakeholders to understand the potential of AV technology for use as an intra-island mobility solution on TI/YBI as well as provide lessons learned for future AVS deployments throughout the city, region, and nation.

2 Referenced Documents

Table 1 contains documents and literature used to gather input for this document.

Table 1: References

Title	Publication Date
California Department of Motor Vehicles - Autonomous Vehicle Deployment (Public Use) Program[1]	2018
California Department of Motor Vehicles - Testing of Autonomous Vehicles with a Driver[2]	2018
California Public Utilities Commission - Autonomous Vehicle Passenger Service Pilot Program[3]	2018
San Francisco County Transportation Authority (SFCTA) Emerging Mobility Evaluation Report	2018
San Francisco Municipal Transportation Agency (SFMTA) - Muni Bus Map	2019
SFMTA, City and County of San Francisco - Advanced Transportation and Congestion Management Technologies Deployment Initiative Grant Application	2016
Treasure Island Development Authority - Treasure Island Transportation Implementation Plan	2011

Source: SFCTA

[1] https://www.dmv.ca.gov/portal/dmv/detail/vehindustry/ol/deployment
[2] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing
[3] https://www.cpuc.ca.gov/avcpilotinfo/

3 Current System

3.1 General

The purpose of this section is to provide context on the situation that has motivated the development of an AVS system on TI/YBI, including the current and planned network infrastructure, its users, and supporting policies and constraints. Sub-sections provide an overview of the goals and scope of the project, review supporting policies and procedures, define current modes of operation, and provide an overview of the users impacted by the current system. Collectively, this section serves to provide a better understanding of the current transportation system.

In the context of this project, the current system refers to the system into which the pilot will be deployed. The island is currently under construction, so the current system is subject to change based on the progress of the Treasure Island development and other projects that may impact the AVS pilot.

3.2 Background, Objectives and Scope

The Treasure Island development is a phased redevelopment project currently under design and construction on TI/YBI. As part of the project, an extensive transportation network has been planned to accommodate the 25,000 new residents on Treasure Island. The residents will generate tens of thousands of trips a day. Due to space constraints, private automobiles will be discouraged on TI/YBI with congestion management strategies, like congestion pricing. The transportation network on TI/YBI will heavily rely on transit services.

As described in the TITIP, once the Treasure Island development is complete in approximately 15-20 years, the island will have multiple bus lines, ferries, a new roadway network, and pedestrian/bicycle facilities. There will be a transit hub located in the southwest area of Treasure Island that integrates all modes of transportation to allow users to transfer among modes of transportation.

Infrastructure and building construction on the island are not expected to be complete until at least 2035 and is implemented in several phases. On-going construction will be taking place on the islands during the testing of the AVS pilot. Therefore, the AVS will be operating on a combination of newly constructed roadways, existing roadways, and roadways that are under construction. Streets may be completed before surrounding amenities, which may still be under construction.

During the pilot, the northeast side of TI will continue to operate as a commercial area, the northwest side will continue to operate as a residential area. The southern end of TI will be closed for construction, with the exception of the Treasure Island Administration Building. The only land use on YBI will be the US Naval Training Station on the east side of the island.

The TIMMA AV Shuttle Pilot Project is anticipated to operate for three months. The goal is to determine whether an AVS or a traditional shuttle serves the mobility goals of the islands better, and what can provide a reliable and positive user experience. During this time, performance will be measured, and lessons learned regarding the efficiencies and limitations of AVS compared to traditional shuttle service will be documented. These outcomes will help to determine whether to consider future AVS deployments on Treasure Island. Confounding factors will be identified in the evaluation plan to ensure that the results are independent of other variables (e.g. changes in land use).

Description of the Current System

The existing transportation services on TI/YBI consist of a roadway network and bus service as discussed below.

3.3 Roadway Network

The roadway network on TI/YBI primary consists of two-lane, two-way roads with stop-controlled intersections. Most existing roads on Treasure Island have sidewalks, while existing 3.3.1 roads on Yerba Buena do not contain pedestrian facilities.

The roadway network on Treasure Island is flat, with grades between 0% and 2%. Yerba Buena contains grades exceeding 12% at some locations. The inter-connecting roadway between the two islands, known as the Causeway, and portions of Macalla Road on YBI, have grades exceeding 17%.

To access the islands, there are ramps to and from YBI connected to I-80, the San Francisco-Oakland Bay Bridge, which passes through YBI in a tunnel.

Prior to and during the AVS pilot, the roadway network on the east side of Treasure Island will be under construction and several roads will be closed. The ramps from I-80 to Macalla Road on YBI will be closed, along with the roads under I-80. The preliminary AVS routes take the road network at the time of the pilot into consideration.

3.3.2 Bus Service

As of December 2019, the existing transit service to TI/YBI is a San Francisco Municipal Railway (Muni) bus line (25 Treasure Island) is a 24-hour daily bus service. It is scheduled to run every 10 to 20 minutes daily with the exception of late night "Owl" service that is scheduled for 30-minute frequency. The primary purpose of the bus service is to get users (residents, workers and visitors) on and off the islands. The service route provides connection between the island and the Salesforce Transit Center located in the East Cut neighborhood in the eastern side of downtown San Francisco. There are 19 existing bus stops on the island. A map of the existing Muni bus service serving TI/YBI, as well as the planned bus service during the time of the pilot, can be found in **Appendix B**. During the construction on the island, the 25 Treasure Island line will be rerouted, and stops will be moved to accommodate the road closures.

The 25 Treasure Island Muni bus serves customers 24 hours a day, seven days a week. The frequency of service is scheduled for 10 to 20 minutes until the late night "Owl" service begins between 12 am midnight to 6am when frequency is scheduled for 30 minutes (as of May 2020). Due to traffic congestion on the San Francisco-Oakland Bay Bridge, the 25 Treasure Island line often experiences reliability issues such as delays and slow travel times.

Existing bus stop infrastructure includes bus shelters at 74% of the stops on Treasure Island. Other stops are marked with a bus zone box in the street or with Muni stop bar and pole markings. An assessment of the existing bus stop infrastructure is planned with the goal of improving amenities and accessibility of these stops wherever possible during the pilot.

3.4 Modes of Operation for the Current System

The following modes of operation establish the operational condition of the current system. The modes, as identified in **Table 2**, are defined as:

Table 2: Definition of System Modes of Operation

Mode	Definition
Mode 1: Normal Operating Conditions	Normal operating condition, the system is operating as designed.
Mode 2: Failure / Degraded Conditions	Situations that require the temporary shutdown or delay of the system.
Mode 3: Maintenance Conditions	The condition of the system where repair is done for an unscheduled breakdown of equipment functionality or scheduled preventative maintenance.

Source: SFCTA

The failure mode can occur when an incident such as a traffic collision or a severe weather event occurs. This could lead to a temporary closure of the roads until they are safe to re-open to traffic, or more commonly delays in Muni service while a bridge incident is cleared. There are two ramps from the San Francisco – Oakland Bay Bridge to the islands so when there is an incident, Muni is often re-routed to the Oakland turnaround and uses the YBI ramp to access TI.

The maintenance mode can occur when the transit vehicles need routine or emergency maintenance.

3.5 Users and Other Involved Personnel

TI/YBI contains a variety of stakeholders, whose diverse needs must be considered during the development of AVS project goals and objectives. Currently, there is no AVS service on TI/YBI or within Muni's service area, so there are no current users of an AVS system. Bus riders living on or commuting to TI/YBI are likely to use a service like the proposed AVS and are considered current circulator users. The transportation system on TI/YBI is utilized by several types of users, all of whom may eventually use the AVS.

3.6 Support Environment

The support environment includes the systems, personnel, and processes that make up the existing transportation system. SFMTA is currently responsible for all the systems, personnel, and the processes associated with the existing transportation system.

4 Justification for and Nature of Changes

4.1 General

This section explains the justification for the development of an AVS service to address TI/YBI mobility challenges. This section begins with a summary of motivations for a new or modified system, before describing and prioritizing the desired changes, including those changes that were identified but not included in this project due to the nature of the pilot. Proposed changes are shaped by the user needs identified throughout the section.

4.2 Operational Policies and Constraints

The TITIP set forth principles and polices that will be carried through the entire Treasure Island redevelopment project. The principles and policies have remained the same and will continue to lay the groundwork for the Treasure Island redevelopment project.

The TITIP describes initiatives that incentivize transit and shuttle use and disincentivize personal vehicle use. These initiatives include congestion management pricing, parking management, ramp metering, transit vouchers, and more. The initiatives also include a free, alternative-fuel, on-island shuttle. This pilot evaluates whether autonomous shuttle technology is viable and desirable to fulfill the planned shuttle service.

4.2.1 Principles

The TITIP defines the redevelopment's future transportation principles as:

- Transportation infrastructure on TI/YBI will be designed around opportunities to safely and comfortably walk and bike as primary modes;
- Transit services to and from TI/YBI will operate throughout the day, evening, and weekends at high levels of service consistent with meeting demand and providing high-quality alternatives to the private automobile;
- Automobile use will be discouraged via parking policies, congestion pricing, and other policies such as ramp metering;
- The plan will be financially viable; and
- Transportation services and pricing will be managed over time to meet the real-time needs of residents, workers, and visitors to TI/YBI.

These principles are intended to guide the overall mobility of the island once the full redevelopment is complete. The principles have informed the development of the pilot but are not directly applicable to this short duration deployment at an early phase of redevelopment.

4.2.2 Policies

The TITIP defines the redevelopment's transportation policies as:

- Prioritize walking
- Maximize the usefulness of bicycling
- Maximize effectiveness and convenience of transit and ridesharing
- Use transportation demand management

- Promote transit
- Improve Bay Bridge ramps

4.2.3 Integration with Sustainability Goals

In addition to the transportation principles and policies, sustainability is a key priority. The Islands' design with the central Transit Hub and shops and dense, transit-oriented land use promotes the use of biking and walking, thereby reducing the number of automobile trips.

4.3 Project Goals

The goals for the project represent the desired result that the project team expects to achieve from the project. The goals are meant to be broad and guide the direction of the project, while the objectives define the specific, measurable targets by which the project team will measure success. Refer to **Appendix A** for the goals and objectives framework.

4.3.1 Safety

For this project, the safety goal is to understand the public safety implications of an AVS without risking safety of the public. Public safety implications may include public perception of safety when riding the shuttle, how often the AVSs disengage, and how often collisions occur. AVSs will be operated without passengers during the operational test period to ensure there are no crashes before passengers are allowed on. It is anticipated that the AVS will be deployed safely during the pilot and is perceived as a safe solution by AVS passengers and road users.

4.3.2 Mobility

In the TITIP, the future transportation needs describe a shuttle service that is needed for the island. The mobility goal is to understand if AV Shuttle technology can meet TIMMA's intra-island transportation service needs at TI/YBI, including allowing for easy circulation for those who choose not to or are unable to walk or bike, connect to transit stops (bus or ferry), serve a majority of land-uses (i.e. can travel throughout the islands), and accommodate bicycles. If the mobility goal is met, then an AVS could serve as a viable alternative to the non-AV shuttles described in the TITIP and become a long-term FMLM solution on TI/YBI.

4.3.3 Operations

The project team aims to understand TIMMA's organizational capabilities and infrastructure needs to operate an AVS. By having a better understanding of the organization and infrastructure needs of an AVS deployment, SFCTA and partner agencies may better recognize other opportunities to deploy AVS in the San Francisco Bay area to solve FMLM challenges.

4.3.4

This goal seeks to explore whether the AVS pilot service is secure, reliable, cost-efficient enough for a full-scale AVS deployment on TI/YBI in lieu of a driven shuttle service, as envisioned in the TITIP, including the need for free service that operates 24 hours a day.

Share Lessons Learned

The final goal of the project is to gather insights from the public during the pilot and share lessons learned with community and key stakeholder (SFCTA, SFMTA, and TIDA). The lessons learned from this pilot will help other community members who may be interested in deploying AVSs. The lessons learned may be posted on SFCTA's website to facilitate community access.

4.4 Project Objectives

The AVS intends to address eight (8) primary objectives as it relates to this deployment. These are captured in **Table 3**. The objectives will be measured to evaluate the success of the pilot. The hypotheses are statements that can be tested to determine the outcome of the objective.

Table 3: Performance Measure Framework

	Objectives	Hypothesis
1A	Protect the safety of passengers & road users in TI/YBI during pilot operations	AV shuttle technology is safely deployed on TI/YBI during the pilot
1B	Explore whether AV shuttle technology can safely navigate the driving challenges of TI/YBI.	The pilot provides data to inform long term decisions about safe AV Shuttle deployments.
		An AV Shuttle is perceived by passengers and road users as a safe long-term solution for TI.
2A	Explore whether AV shuttle service can be accessible to everyone	AV shuttles are capable of serving individuals with disabilities, including people using wheelchairs, without human assistance.
		AV shuttles are not a barrier to disadvantaged or vulnerable users[4].
		AV shuttles can carry bicycles and personal transportation devices, strollers & luggage or operator has a roadmap to provide accommodations under full deployment.
2B	Explore the AV shuttles' ability to meet the intra-island needs of users in TI/YBI	AV shuttle service can meet TI/YBI user needs.
3A	Explore whether AV shuttle technology can meet TIMMA's TI/YB shuttle operation needs	AV shuttle operations are secure from cyber-attacks.
		AV shuttle operations can provide accurate, reliable and timely data.
		AV shuttle operation costs are equal or less than other similar public services.
3B	Explore whether AV shuttle technology can meet TIMMA's TI/YB shuttle service needs and constraints	AV shuttles can meet TIMMA's shuttle service requirements.
		AV shuttles can provide reliable (without disruptions) service.
		AV shuttle operator will meet or have a roadmap to meet CA public fleet emission goals (all electric by 2040).

[4] Disadvantaged or vulnerable users includes users who are vision impaired, mobility impaired, or otherwise disabled or socio-economically disadvantaged.

	Objectives	Hypothesis
4A	Provide opportunity to demonstrate AV technology to key stakeholders and community groups through pilot.	The AV pilot is a learning opportunity for key stakeholders and community groups.
4B	Upon pilot completion, pilot results are shared with stakeholders	AV pilot outcomes are collected and shared with stakeholders.

Source: SFCTA

4.5 Essential Features

This section identifies the User Needs of the AVS project. Many needs were identified based on the established project goals and objectives (see Appendix A), discussion with SFCTA, SFMTA, Treasure Island Development Authority (TIDA), and guidance on behavioral competencies for highly autonomous vehicles from the Federal Automated Vehicles Policy. Additional needs were added in consideration of this being a public service, both from the passenger perspective and as additional desired capabilities of the AVS shuttle. User needs were also derived from existing Treasure Island development goals, project meetings, and existing documents.

Table 4: User Needs

Identification	Title	Description	Rationale
AVS Passenger Needs			
AVS-UN001-v01	Boarding AVS	An AVS passenger needs the AVS to stop and open its door at designated locations to board the AVS.	To start a passenger trip.
AVS-UN002-v01	Alighting AVS	An AVS passenger needs the AVS to stop and open its door at designated locations to alight the AVS. The vehicle must be able to stop and open doors for a passenger emergency.	To end a passenger trip.
AVS-UN003-v01	Traveler Information	An AVS passenger needs information on the AVS's route, status, schedule, and next stop to make travel decisions. Information must be conveyed both visually and audibly.	To allow passengers to plan for start and end of a trip and effectively use the shuttle service.

Identification	Title	Description	Rationale
AVS-UN004-v01	Passenger Safety Alert	An AVS passenger needs to be able to alert the Vendor's AVS Management System[5] when there is an issue on board the AVS. Also provide first aid kit/fire extinguisher within the AVS.	To be able to respond in the event of an emergency, criminal activity, or other safety concerns.
AVS-UN005-v01	Concierge	An AVS passenger needs to be able to be greeted and given instructions, if necessary, when boarding or alighting the AVS.	To improve safety and customer service of the AVS system. Note that the safety driver and concierge may be the same person.
AVS-UN006-v01	ADA Accessibility	An AVS passenger that uses a mobility device needs to be provided with a method to safely board, alight and secure their device.	To ensure the safety of passengers with disabilities using the AVS.
AVS Needs			
AVS-UN007-v01	Stop for Passenger Boarding	The AVS needs to know where to stop to pick up passengers.	To start a passenger trip and provide a shuttle service. For this project, the shuttle will stop at every designated shuttle stop. Optionally, there may be an app that will allow for skipping stops.
AVS-UN008-v01	Stop for Passenger Alighting	The AVS needs to know where to stop to drop off passengers.	To finish a passenger trip and provide a shuttle service. For this project, the shuttle will stop at every designated shuttle stop. Optionally, there may be an app that will allow for skipping stops.

[5] Throughout this document AVS Management System refers to the vendor's back-office management system overseeing the shuttle operation.

Identification	Title	Description	Rationale
AVS-UN009-v01	Ridership data	The AVS needs to collect ridership data.	To understand AVS utilization, passenger counts may be collected by an Automated Passenger Counter (APC) or a concierge.
AVS-UN010-v01	ADA Accessibility	The AVS needs to know when to deploy a ramp or activate other equipment to allow for riders with disabilities to use the AVS	To facilitate people who are boarding and alighting without concierge support.
AVS-UN011-v01	Quiet Car Alert	The AVS needs to emit an alert sound to warn pedestrians. The AVS needs to make itself visible with lights.	To alert pedestrians, bicyclists, and other road users of an on-coming AVS.
AVS-UN012-v01	Manual Fueling	The AVS needs to be able to be manually connected to a charging source if electric or fueled if another fuel source is used.	To recharge the battery or refuel the vehicle.
AVS-UN013-v01	Transportation Management System	The AVS needs to have an on-board transportation management system.	To collect data on the AVS location, to support Traveler Information and comfort, to meet AVS passenger user needs, and to provide data to support performance measures
AVS-UN014-v01	Security Camera	The AVS needs to have an on-board and outside video camera installed and video transmitted to the AVS Management System.	To monitor the inside and outside of the vehicle for security purposes.
AVS-UN015-v01	Law Following – Open Traffic Environment	The AVS needs to be able to detect other street users, objects and vehicles on the public roadway, classify those objectives correctly, predict their path, accurately plan a traffic maneuver and execute such maneuver.	To safely navigate the roadway, interact with other road users in mixed traffic, and not cause, directly or indirectly, traffic collisions.

Identification	Title	Description	Rationale
AVS-UN016-v01	Law Following – Regulatory	The AVS needs to have knowledge of and the ability to follow local, state, and federal driving laws, including the ability to detect and understand regulatory signs, speed laws, pavement markings, and traffic signals.	To operate in compliance with traffic laws.
AVS-UN017-v01	Law Following – Temporary Traffic Control	The AVS needs to be able to detect and respond to detours, humans directing traffic, and other temporary changes in traffic patterns.	To operate in compliance with traffic laws, even when conditions have deviated from the everyday. Safety driver may need to assume control during the pilot.
AVS-UN018-v01	Route Deviation	The AVS needs to be able to deviate from its specified route when necessary and safe.	To safely operate in case a detour is required from the route specified by the AVS Management System or safety driver.
AVS-UN019-v01	Crash Avoidance	The AVS needs to be able to detect an imminent collision and respond to avoid the collision or minimize the impact, in a manner that does not put passengers at risk of injury. The AVS must include an event data recorder that has the capacity to retain data according to the standards in 49 CFR 563, as well as additional data consistent with 2020 SAE standards for AV data loggers.	For crash avoidance and impact minimization in the event of control loss, an imminent collision, or road departure situations.
AVS-UN020-v01	Fall Back	The AVS needs to be able to safely operate when it's faced with abnormal conditions, such as with a malfunctioning detector, in an unfamiliar environment, or after an incident has occurred.	To inform the AVS Management System, minimize risks, stop at a safe location, and remove itself out of service if needed.

Identification	Title	Description	Rationale
AVS-UN021-v01	Detection Arbitration	The AVS needs to be able to arbitrate between detected concurrent regulatory signs, pavement markings, traffic signals, human traffic control gestures, and object detections.	To determine the safest and most legal course of action, when confronted with multiple inputs.
AVS-UN022-v01	Disengagement Mechanism	The AVS must be able to disengage from autonomous mode.	To allow the safety driver to take manual control
AVS-UN023-v01	Uncertainty in Course of Action	The AVS needs to be able to decrease speed and pull over in a legal stopping location, if safe, when there is uncertainty regarding which action to take.	To minimize the likelihood of a potential incident or the impact of an incident.
AVS-UN024-v01	Operational Design Domain	The AVS needs to verify its Operational Design Domain and restrict operations if operated outside its Operational Design Domain.	To prevent the AVS from operations outside its intended domain.
AVS-UN025-v01	Climate Control	The AVS needs to support climate control within the vehicle.	To increase comfort of the AVS occupants.
AVS-UN026-v01	Tow or Road Clearance	The AVS needs to be able to safely be towed in the event the vehicle is immobilized and needs to be cleared from the roadway.	To ensure the safety of those towing the vehicle and reduce the risk of damaging the AVS.
AVS Management System Needs			
AVS-UN027-v01	Route Definition	The AVS Management System needs to be able to program the operating routes into the AVS.	To tell the AVS where to travel during normal operations.

Identification	Title	Description	Rationale
AVS-UN028-v01	End of Service Period	The AVS Management System needs to end service by terminating at its pre-determined storage spot at the end of the service period.	This allows the AVS to return to the storage area for charging and planned maintenance without inconveniencing the passengers. This will improve customer satisfaction but is not essential to service provision. The AVS may stop in a pre-determined location and be driven to the storage spot by the safety driver. This includes maintaining an emergency fuel reserve to return to the charging/fueling facility
AVS-UN029-v01	Managed AVS Operations	The AVS Management System needs to manage operations, ensuring the AVSs are running on schedule and minimizing conflict with existing Muni service.	To provide a reliable service to passengers and to ensure proper operations of the AVS.
AVS-UN030-v01	Data Transfer	The AVS needs to be able to transfer safety operations and trip data to the AVS Management System and any other designated databases for City analysis.	To analyze the successful performance of the AVS on multiple dimensions. While the data transfer to the AVS Management System is required, transfer to designated databases for City analysis is a desired feature.
AVS-UN031-v01	AVS Charge	The AVS Management System needs to be able to maintain power throughout the operational period to ensure consistent operations on its routes.	To continuously provide service during hours of operation.

Identification	Title	Description	Rationale
AVS-UN032-v01	AVS Operation Monitoring	The AVS Management System needs to be able to monitor the status of the AVSs.	To determine when a degraded or failure condition has occurred.
AVS-UN033-v01	Managed AVS Charging	The AVS Management System needs information on the AVS's battery level, ensuring the AVSs are sufficiently charged.	To mitigate the risk of an unexpected loss of power.
AVS-UN034-v01	Incident Response	The AVS Management System needs to communicate to the AVS Management System and have contingency plans to respond if an incident does occur.	To communicate incidents immediately and plan an appropriate response to incidents and minimize additional risks afterward.
Operations Staff Needs			
AVS-UN035-v01	Manual AVS Operation	Operations staff need to be properly trained on how the AVS technology works, emergency response protocols and how to manually control the AVS if deemed necessary.	To assist the AVS conditions it is unable to negotiate, to minimize risk, and to comply with AV regulations. Note that the safety driver and concierge may be the same person.
AVS-UN036-v01	Assistance for People with Disabilities	Operations staff need to be able to properly secure people who use mobility devices and assist with boarding and alighting.	To ensure the safety of passengers that use mobility devises.
AVS-UN037-v01	AVS Override / Shut Off	Operations staff, when near the AVS, need to be able to safely stop and turn off the AVS.	So that the operations staff can override any other controls the AVS is receiving, which may be faulty or malicious, and bring the AVS to a safe stop before determining the next course of action.

Identification	Title	Description	Rationale
AVS-UN038-v01	Manual Data Collection	Operations staff need to be able to properly collect information on passenger information and operations data.	To be able to calculate performance metrics for data that can't be collected without human assistance, including, but not limited to, number, location, and cause of AV system disengagements; user and non-user surveys; number of times people with disabilities were able to hail, board, secure themselves, or alight without requiring concierge assistance and with assistance; and number of bicycles on board the AVS.

Source: SFCTA

4.6 Desirable Features

The following user needs have been considered but are not deemed as requirements during the pilot. The features are considered desirable and may be considered during the evaluation of vendors.

Table 5: Optional User Needs

Identification	Title	Description	Reason for not Including
AVS Needs (Desired Capabilities)			
AVS-UN039-v01	Stop for Passenger Boarding (On-Demand)	The AVS needs to know where to stop to pick up passengers.	AVS will have a fixed route. On-demand location may not be ADA compliant. However, services may be provided on-demand (at any time based on user request) within the fixed route.
AVS-UN040-v01	On-Demand Stop for Passenger Alighting (On-Demand)	The AVS needs to know where to stop to drop off passengers.	AVS will have a fixed route. On-demand location may not be ADA compliant.

Identification	Title	Description	Reason for not Including
AVS-UN041-v01	Fare Collection	The AVS needs to have the ability to collect fares on board with a system compatible with a Common Payment System and Multi-modal Trip Planning App.	AVS will be free to ride during the pilot.
AVS-UN042-v01	Automatic Charging	The AVS needs to be able to connect to a charging source independently of human assistance from the operations staff.	Alternatively, AVS will have operations staff who can manually charge the AVS.
AVS-UN043-v01	Minimize Travel Time	The AVS Management System needs to optimize route operations and minimize passenger travel time by limiting dwell times and maintaining consistent travel on its route.	Alternatively, dwell times and operating speed will remain constant or modified as needed by the on-board concierge and as road conditions allow.
AVS-UN044-v01	Minimize Transfer Time	The AVS Management System needs to minimize passenger waiting time at shuttle stops shared with fixed route transit by timing AVS arrivals with Muni schedule at terminal and major hubs.	It is not essential to the pilot to time the AVS to the Muni schedule.
AVS-UN045-v01	Coordinate with Signals (DSRC) - TSPS	The AVS needs to have an Onboard Unit using Dedicated Short-Range Communications (DSRC) to interface with the Roadside Units using DSRC at the intersections within the operating area.	Signals will not be installed prior to pilot.

Identification	Title	Description	Reason for not Including
AVS-UN046-v01	Environmental Condition Monitoring	The AVS Management System needs to be able to monitor local weather patterns and be aware of an approaching severe weather event or other conditions that may impact AVS operations.	Alternatively, AVS will have a concierge on board who can determine if the AVS needs to suspend operations.
AVS-UN047-v01	24/7 Operations	The AVS will operate around the clock provided service.	Based on existing Muni operations and TI/YBI growth during the pilot period, it is anticipated that ridership will be too low during pilot period to justify cost of 24/7 operations.
AVS-UN048-v01	Hybrid Vehicle	The AVS will be able to operate all-electric or as a hybrid with other fuel type.	All-electric or hybrid vehicles are preferred for the project, but the project is open to other options to not limit vendors.
AVS-UN049-v01	Bike Racks	The AVS will have bike racks	Bicycles, as well as other devices like wheelchairs, walkers, and strollers, can be brought onto the AVS.
AVS-UN050-v01	Free Wi-Fi	The passengers will have Wi-Fi connectivity within the shuttle	Not in line with project goals and objectives.
AVS-UN051-v01	Multi Modal Trip Planning App	Passengers can receive the real-time AVS location and plan a trip based on the AVS location.	It is optional for the pilot. Also, the AVSs are not integrated into other modes of transportation during the pilot.

Source: SFCTA

5 Concepts for the Proposed System

5.1 General

This section provides more detail on the concepts of the AVS system and how it supports the goals of SFCTA. The following sub-sections cover background, operational policies and constraints, a description of the proposed system, modes of operation, stakeholder roles and responsibilities, users, other involved personnel, the support environment, and security and privacy concerns.

5.2 Background, Objectives and Scope

The goal for this AVS project, in line with program-level goals established in the TITIP, is to determine whether AVS shuttle service is an effective and financially viable high-capacity transportation solution for TI compared to traditional shuttle service, and that is affordable to operate, promotes walking and biking and may one day encourage car-light living, meaning residents choose to rely less on personal automobiles and opting for alternative transportation modes like walking, biking, riding transit or carpooling.

These goals and objectives are supported by the following metrics:

Objective 1A: Protect the safety of passengers & road users in TI/YBI during pilot operations:

- Number of collisions and incidents (including injuries)
- Rate of incidents/collisions per mile of operation

Objective 1B: Explore whether AV shuttle technology can safely navigate the driving challenges of TI/YBI:

- Number, location and cause of AV system disengagements (including operating system malfunction or shut down due to an unknown operating parameter or safety driver assuming control of the vehicle) and other potential safety incident (including number, location and context of situations when the shuttle encountered safety events and didn't disengage)
- Perceived personal safety and overall system safety when riding or encountering shuttle

Objective 2A: Explore whether AV shuttle service can be accessible to everyone:

- Number of times people with disabilities (by category of disability) were able to hail, board, secure themselves or alight without requiring concierge assistance. Number of times concierge assistance was required to hail, board, secure or alight (to derive a rate of success). User perceptions of all trip elements (including hailing or reservation system) from persons with disabilities through user survey.
- Vulnerable or disadvantage user perceptions, measured through before and after user survey.
- Number of bicycles on board the AV shuttles. Number of times bicyclists could not board due to capacity. User survey of ease of use for bicycles, personal transportation devices, strollers & luggage.

Objective 2B: Explore AV Shuttle's ability to meet the intra-island needs of users in TI/YBI:

- AV Shuttle service use and perceptions as measured through user and non-user survey

Objective 3A: Explore whether AV shuttle technology can meet TIMMA's TI/YBI shuttle operation needs:

- Percentage of time during operating hours the system is shut down due to operating system security breaches. Number of security breach attempts & number of successful breaches.
- Data is received accurately, per standards and on time.

Annualized operating expense per service mile. **Objective 3B: Explore whether AV shuttle technology can meet TIMMA's TI/YBI shuttle service needs and constraints:**

- Adherence to operating and performance requirements that are accurate with timely reporting of data (operating hours, ridership, disengagements, safety, emissions)
- Actual hours in service as compared to anticipated scheduled hours of service. Dwell times by stop and route durations histograms. If on-demand, percentage of requests fulfilled, response time histogram. Percent of time during operating hours, the system is out of service and cause of service disruption.
- Number of electric, hybrid or alternative fuel vehicles in pilot. Grams CO2 per passenger mile (if not Zero Emission Vehicle) consistent with California Air Resources Board regulations. Year operator would be able to meet CA public fleet emissions goals.

Objective 4A: Provide opportunity to demonstrate AV technology to key stakeholders and community groups through pilot:

- Number of total people participating in a demonstration to key stakeholders and community members

Objective 4B: Upon pilot completion, pilot results are shared with stakeholders:

- Key participant end of pilot survey

5.3 Operational Policies and Constraints

Vehicles in the pre-deployment system are all human operated, and a significant change to the proposed system is the addition of autonomy. There are various policies and procedures that have been adopted, published, or currently within rulemaking that govern the use of autonomous vehicles in the state of California and the United States. These include:

- Federal Automated Vehicles Policy, published by the USDOT and the National Highway Traffic Safety Administration (NHTSA) in September 2016, provides guidance for developing an approach to automated vehicle performance specifications, the roles delegated to states, and current and proposed regulatory tools to maintain safety in this new transportation environment while not restricting technological innovation.
- Federal Motor Vehicle Safety Standards (FMVSS), also developed by NHTSA, regulate features required for vehicles operated on public roads, in categories such as crash

avoidance, crashworthiness, and post-crash survivability. Exemptions are required for vehicles without human controls.

- The State of California has passed legislation that allows autonomous vehicles that comply with FMVSS to be operated on public roadways if a permit is issued for the vehicle by the California DMV.
- The State Public Utilities Commission has authorized two pilot programs for the private prearranged transportation of passengers in test AVs. The AV vendor will need California Public Utilities Commission approval for the deployment.

Automated vehicle technologies are an emerging field and the technology is still under development. The AVS vendor must comply with FMVSS or seek a federal exemption. The vendor must also obtain the appropriate testing permits from the state for testing on public roads and for providing passenger service. These existing regulations and any potential changes or opportunities for exemptions will continue to be monitored by the vendor during the pilot.

The AVSs will be traveling on roads with mixed-traffic, and even in cases where the roads are closed for testing, they will need to be able to detect and respond to traditional regulatory signs. In addition, the streets along the route may be under construction during portions of the pilot. The vehicle or on-board operator will need to respond to temporary signage and flagmen accordingly.

The AVS will likely operate on the same streets and may use the same stops as the Muni 25 Treasure Island. Muni Transit Planning must be consulted on proposed AV bus route alignments on Treasure Island and shared use of bus stops.

5.4 Description of the Proposed System

To see how AVSs could be a potential long-term FMLM solution on TI/YBI, the pilot will deploy AVSs on TI/YBI before the Treasure Island development construction is finished. These AVSs will be deployed in a live mixed-used traffic environment, interacting with other vehicles, bicyclists, pedestrians, and other forms of transportation, and operating in an environment that includes unsignalized intersections. This approach intends to bring a safe, efficient, accessible, environmentally friendly, and easily expandable transportation solution to the region by deploying a fleet of multi-passenger AVSs. The AVSs will serve a route that is designed to meet the transportation needs of the area.

At a high level, this project could be described as a transportation solution that uses an AVS. The strategy to approach this project could therefore be separated into two parts: the transportation component and the automated driving system component. The components also have policy aspects – policies that govern how transit should be introduced and how it should serve all users, and policies that govern the rules for deploying autonomous vehicles in mixed traffic on public roads. These components also have subcomponents, which are described in the following subsections.

5.4.1 Interfaces

5.4.1.1 Passenger Interfaces

A major need of the AVS passengers is to be able to board and alight the AVS, in fact, a viable service will not be possible if this need is not met. The simplest way to accomplish this will be to program the AVSs to stop at every pre-programmed stop along their route. If this procedure is pursued, an interface to passengers will not be necessary. An on-board interface could also provide information on local attractions, weather, and other information or advertisements, if possible, to enhance passenger experience.

AVS passengers would also benefit from information on the AVS's route and current location. This will be provided from the AVSs directly, via static maps, on-board information, and potentially electronic signs at stops that are accessible to all passengers. AVS passengers will also be able to communicate directly with operations staff, as they will be stationed as a concierge on the AVSs.

5.4.1.2 Charging/Maintenance Interfaces

The AVS will also need to interface with the charging, storage, and maintenance facility. If the shuttle is capable of automated charging, the shuttle will activate the facility in order to enter and exit at the beginning and end of the service period. If the shuttle has manual charging, the concierge will store the vehicle and plug it in to charge.

5.4.1.3 Operations Interfaces

The AVSs will send the AVS Management System information on their current operating status. The AVS Management System will be able to override the AVS and bring it to a stop, as will operations staff, but they will only be able to drive the AVS if they are physically present in the vehicle.

If the vendor's AVS Management System and SFMTA have the ability, SFMTA and the AVS Management System may communicate current vehicle location information, which will facilitate transfers, but this is not an essential capability.

If the vendor has the ability to send operations and trip data to other designated databases for City analysis, the vendor will send information from the AVS Management System to the databases for archiving and analysis.

5.4.1.4 Road User Interfaces

The AVS will need to interact with road users in order to operate. Other vehicles, bicycles, pedestrians, scooters, construction equipment, and other users will be detected via outboard sensors on the AVS. Road users will visually and audibly detect the vehicle approaching. The vehicle will meet the minimum required USDOT noise requirement to make the vehicle detectable to visually impaired road users.

5.4.2 Vehicles

The AVSs will not be designed or built by TIMMA but procured from an external vendor and leased for use on the islands during this pilot. If purchased, USDOT requires vehicles comply with Buy America requirements, which is difficult to achieve by vendors that meet federal and California regulatory requirements. However, it is likely that any vehicle will require some customization for this project. Current AVS have maximum speeds of around 25 mph and provisions for some ADA accessibility for other projects around the country. ADA provisions for the vehicle include those that fall under Title 49 Part 38 Subpart B[6].

The proposed AVSs will incorporate the latest AV technologies available. They must also be able to be fully recharged during the amount of time they are out of operation. Assuming the AVSs operate for 13 hours a day, which may change depending on the final route alignment and schedule, they must also be able to be fully recharged in fewer than 11 hours.

The number of AVSs required for the project will be vendor-specific and determined as part of the proposal. Vendors will be required to meet a headway and hours of service. Each vendor will propose a number of AVSs based on their AVS speed capabilities and battery capacity. It's anticipated that approximately four shuttles will be required to operate the service.

Each AVS is expected to include in-vehicle and outside cameras to be used in cases of emergency or security situations. If possible, footage will be transmitted centrally, and at a minimum it will be uploaded nightly and available for the project team to review when the AVS returns to the charging and maintenance facility. Occupancy will be limited to the maximum weight capacity of the AVS and on-board sensors will be used to detect weight. All AVSs will also be outfitted with seat belts, an emergency button or call box, internal visual and audible indicators. The AVSs will be equipped with robust vehicle health and status monitoring capabilities, a sophisticated obstacle bypass algorithm, and for worst-case scenarios, will have the ability to be operated by a trained human operator. In order to operate in mixed traffic, the AVSs will need to be road legal and compliant with the crashworthiness and other standards set by the FMVSS and appropriate State permits.

The AVSs are expected to be able to operate in minor inclement weather (e.g. light right or high visibility fog), but major adverse weather conditions will require the operator to suspend service. Major weather conditions that could affect service include thunderstorms, earthquakes, and heavy fog.

5.4.3 Route Development Methodology and Proposed Routes

Operationally, the intent is to deploy AVSs on TI/YBI. These AVSs will be deployed to serve two types of trips: transfer trips from the Transit Hub to area destinations and circulator trips within TI/YBI area, with usage independent of how the passenger traveled to TI/YBI.

The plans outlined in the TITIP (as shown in **Appendix C**) include three fixed routes, with the routes being combined into one route at night, and the routes being extended to remote areas on weekends. These routes were designed to serve the retail, commercial, and residential areas and to create a connection to the Transit Hub. Only Phase 1 of the development will be completed by the time that the AVS pilot begins and roads for the next phase will be closed or under construction.

The preliminary routes for the pilot have been developed and can be found in **Appendix D.** It is expected that the AVS service will operate from 7:00 AM to 8:00 PM for weekdays and 7:00

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6 https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&rgn=div5&view=text&node=49:1.0.1.1.28&idno=49#sp49.1.38.b

AM to 5:00 PM on weekends. The routes will be finalized after the procured vendor has tested the vehicle on the route.

Throughout the pilot, roads may periodically be under construction and require rerouting of the shuttle or response to temporary traffic control.

5.4.4 Accessibility

The vehicles must be accessible to those with disabilities. Onboard operators will be on board each vehicle during the pilot, and they may provide assistance to passengers beyond what the vehicle is independently capable of (such as securing a wheelchair or providing audible alerts). Accessibility requirements and desirable accessibility feature, including onboard staff training, will be incorporated into the vendor selection process. The vendor will be required to identify its ability to comply with all applicable requirements of the Americans with Disabilities Act of 1990 (ADA), 42 U.S.C. 12101 et seq. and 49 U.S.C. 322; Section 504 of the Rehabilitation Act of 1973, as amended, 29 U.S.C. 794; Section 16 of the Federal Transit Act, as amended, 49 U.S.C. app. 1612; and the following regulations and any amendments thereto:

- USDOT regulations, "Transportation Services for Individuals with Disabilities (ADA)," 49 CFR. Part 37;
- USDOT regulations, "Nondiscrimination on the Basis of Handicap in Programs and Activities Receiving or Benefiting from Federal Financial Assistance," 49 CFR. Part 27;
- US. DOT regulations, "Americans With Disabilities (ADA) Accessibility Specifications for Transportation Vehicles," 49 CFR. Part 38;
- Department of Justice (DOJ) regulations, "Nondiscrimination on the Basis of Disability in State and Local Government Services," 28 CFR. Part 35;
- DOJ regulations, "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities," 28 CFR. Part 36;
- General Services Administration regulations, "Construction and Alteration of Public Buildings," "Accommodations for the Physically Handicapped," 41 CFR. Part 101-19;
- Equal Employment Opportunity Commission (EEOC) "Regulations to Implement the Equal Employment Provisions of the Americans with Disabilities Act," 29 CFR. Part 1630;
- Federal Communications Commission regulations, "Telecommunications Relay Services and Related Customer Premises Equipment for the Hearing and Speech Disabled," 47 CFR. Part 64, Subpart F; and
- FTA regulations, "Transportation for Elderly and Handicapped Persons"

5.4.5 Infrastructure Upgrades

Infrastructure upgrades including installation of electric charge stations (for electric vehicles) and establishing a storage maintenance facility may be required to operate the AVSs on TI/YBI existing and future roadways. In addition, although small improvements may be needed to operate the AVSs, roadway construction, ADA ramp updates and shuttle stop infrastructure will not be a part of the TIMMA AV Shuttle Pilot Project. Infrastructure upgrade installation, if necessary, will most likely be the responsibility of TIDA (with inputs from the vendor).

Upgrades may also include bus stop infrastructure. This could be as simple as a temporary sign or as complex as a covered stop, particularly for shared stops with SFMTA. The shuttle stop signage may convey the stop location name, approximate stop times, and headway.

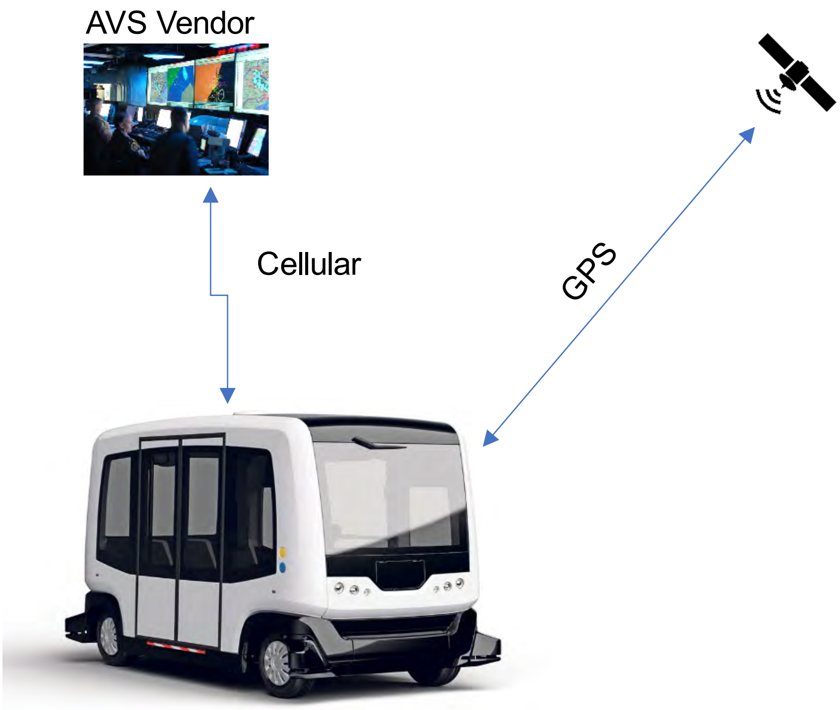
Maintaining the upgrades during the pilot will also be critical for sustained operational performance.

5.4.6 Communications

The AVS is expected to use 4G Long Term Evolution (LTE) and backhaul communications to facilitate the transfer of data associated with the system. 4G LTE is a wide-area wireless technology commonly used by transit agencies to provide communications between the transit management center and the AVS. 4G LTE communications are expected to be utilized for communications between the AVSs and the AVS Management System to support management of the service and any real-time information distribution. AVS status information, roadway conditions, and weather conditions will be transmitted via 4G LTE between the AVS and the AVS Management System. It is not anticipated that there will be communications between the AVS Management System and the communication centers of any other agencies. In the event of an emergency onboard the shuttle, the AVS Management System or onboard staff will contact the San Francisco Police Department to send first responders to the scene.

Satellite communications will be used for the transmission of time and location data from Global Navigation Satellite System (GNSS) satellites to the AVS. A high-level diagram of the communications is depicted in **Figure 1**.

Communications between other objects and users in the system will be physical in nature – this includes operations staff taking control of the AVS (when necessary), communications between operations staff and AVS passengers (on-board the AVS or at an AVS stop), route information on the AVS (static and audio), boarding and alighting the AVS, and the ability of the AVS to detect physical objects on the road and on the roadside.



Source: SFCTA

Figure 1: Proposed AVS System

5.4.7 Facilities

Based on the Route 25 Treasure Island line service map during the pilot and the preliminary shuttle routes, the AVSs will share stops with SFMTA buses. Any stops that will be served by the AVSs will need appropriate signage and need to be ADA accessible. SFMTA and TIDA will evaluate for ADA compliance and complete the associated work prior to the pilot.

A building for the purpose of maintenance, storage, and charging facility for the AVSs may be necessary. Electric utility service will be required for the charging stations.

The AVS Management System will be responsible for remote monitoring of the service and other administrative tasks. The AVS Management System will require an operations center for AVS service oversight. The maintenance, storage, and charging facility may also need to house the AVS Management System physical operations center. Alternatively, the operations center may be in a remote location maintained by the vendor. The staff in the operations center will be responsible for monitoring the status of the operations, managing the service, and communicating with concierge and passengers in the event of an incident. The back-office monitoring service will also serve to collect and forward all applicable data associated with operation of the AVS fleet.

Preliminary locations for the maintenance, storage, and charging facility may be the basement of One Avenue of the Palms or a temporary facility may be built in an empty parking lot on TI/YBI. Coordination with the vendor will be needed to select a location for the facility. The building or space will be made available by TIDA.

5.4.8 Customer Service & Incident Management

During operating service, incidents that are of potential concern often require a vehicle operator to radio for assistance. In an autonomous environment, vehicle operations could begin by hosting a concierge (operations staff) on each of the AVSs. For this pilot, the concierge and safety driver may be the same person. That person would play the role of the safety driver while the vehicle is in motion and the concierge while the vehicle is stopped. The focus of the dual role is safety, and protocols will be established so that safe operations are the priority.

5.4.9 Physical Security

The AVSs are expected to have an on-board mechanism such as a safety alert button that will allow passengers to communicate with the AVS Management System and operations staff if they believe their conditions are unsafe. This could include criminal activity and passenger medical emergencies, as well as AVS malfunctions. On-board operations staff or a concierge will be on board to fill this role and will need to be aware of any concerns, be cognizant of users' perspectives, and respond appropriately.

AVSs and their on-board devices and external detection equipment will need to be physically protected to reduce the chance of theft or unauthorized access to these devices. The proposed maintenance, storage, and charging facility by the vendors will fulfill this purpose during non-service hours. The AVSs will have on-board and external video cameras, as well as an on-board concierge, to ensure that the vehicle remains secure.

5.4.10 System / Data Security

The AVSs will not be able to be operated remotely due to the risks involved, including network security risks. Passengers will also not be able to steer the AVS while on board. If an on-board steering wheel and brakes are installed, it will be accompanied by trained operations staff.

The system will use LTE for monitoring the AVSs and receiving and providing real-time transit information. The system will adhere to security standards for LTE communications, including 3GPP TS 33.401 V14.2.0 (2017-03) – 3GPP System Architecture Evolution (SAE); Security architecture[7]. The system will also have to handle potential GPS spoofing, which will be supported by the redundant systems for vehicle routing and location detection.

5.5 Modes of Operation

The modes of operation, as introduced in Section 3.4, specifically for the new AVS system are as follows:

[7] https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2296

Table 6: AVS System Modes of Operation

Mode	Definition
Mode 1: Normal Operating Conditions	Normal operating conditions. All AVSs in the fleet are operating on their routes as designed. The AVSs detect and respond to objects and other road users while they travel between stops. At the stops, the vehicle allows passengers to board and alight and offer visual and audible cues to passengers. The AVSs have the charge available to complete their operations. When scheduled charging does occur, an AVS returns to the storage area or to a charging station and safely obtains the needed charge. When daily operations are completed, all AVSs return to the storage area after allowing all on-board passengers to alight at their desired stop. If severe weather or another event occurs and the AVSs are safely taken out of operation before any incidents can occur, while the shuttle service is no longer operational, the AVSs are considered to be operating as intended.
Mode 2: Failure/ Degraded Conditions	Everyday operations have been degraded from the normal operational state. Degraded conditions include traffic causing the shuttle service to be behind schedule, high demand causing the AVS to be at or above capacity, or an AVS running out of charge unexpectedly and needing to return to a charging station immediately. It also includes a system component, such as the automatic charging capability, not working as designed and the system needing to revert into a lower state, in this case manual fueling. The degraded mode also includes passenger safety issues that have caused a passenger alert to be called to the AVS Management System, or the AVS Management System otherwise being alerted that the AVS needs additional monitoring or for operations staff to assist. Severe weather conditions that impact the safety of the vehicles are also included if the AVS is not removed at the point conditions reach an unsafe state outside the scope of the AVS's safe operating conditions. A failure condition occurs if the AVS is not able to make it to a charging station before losing charge, if the AVS has an interaction with a public safety official who believes it is operating in an unsafe manner, if there is an AVS malfunction that could cause additional issues, or if a collision involving the AVS or another incident has occurred. In these cases, operations staff will need to be involved for the AVS to return to a degraded or operational state. In the event of a collision or other incident involving the AVS, operations will be suspended until a cause and mitigation can be established. In the event that AVS operations are suspended, backup non-AV shuttle transportation will be provided by the AVS vendor.
Mode 3: Maintenance Conditions	The AVSs will be regularly checked for any issues. If an issue is detected during routine maintenance, a preventative measure must be scheduled. If an emergency breakdown occurs, the AVS will be taken out of service and repaired by the appropriately trained entity. If operations are ongoing and a spare AVS is available, the AVS undergoing maintenance will become the spare vehicle and service will continue as regularly scheduled.

Source: SFCTA

5.6 Users and Other Involved Personnel

Users for the new AVS system are presented in **Table 7**.

Table 7: Users and Applicable Groups

Users	Applicable Groups	Role
AVS Passengers	TI/YBI Residents, Employees, and Visitors	Service user
AVS Management System	Transportation Operations and Management Entity	Manage service operations and data
Operations Staff	Staff hired by the AVS Management System to perform tasks for the AVS that require human assistance, including concierge and safety driver roles. This also includes maintenance staff for maintaining and charging the vehicles.	Assist passengers and operate AVS

Source: SFCTA

Other involved personnel, who are not direct users of the AVSs but will interact with the AVS system include:

Table 8: Other Involved Personnel

Users	Applicable Groups	Role
Bicyclist	Other TI/YBI Residents, Employees, and Visitors	Interact with AVS
Pedestrian	Other TI/YBI Residents, Employees, and Visitors	Interact with AVS
Emergency Vehicle / Emergency Vehicle Operator	Police (San Francisco Police Department), Ambulance, Fire (San Francisco Fire Department)	Respond to incidents
SFMTA	Sustainable Streets, Accessible Services, Transit, System Safety, Information Technology	Operate Muni service
SFCTA	Planning, Capital Projects, Finance and Administration	Project management, funding, and planning
TIDA	Development, Construction and ongoing operations (events, etc.)	Manage development, construction, and ongoing island operations
TICD	Development, Construction	Manage development and construction

Source: SFCTA

5.7 Support Environment

The project will be supported by several local and federal agencies. These agencies will support various roles during pilot development and delivery. **Table 9** shows the roles of these agencies.

Table 9: Support Environment

Pilot Development/Delivery	Lead Agency	Support Agency
Conceptual Design	TIMMA (Approver)	TIDA/SFMTA
Concept of Operations	TIMMA	SFMTA/TIDA/FHWA(Approver)
Route Planning	TIDA	TIMMA/SFMTA
Requirements	TIMMA	SFMTA/TIDA
RFP Development	TIMMA	SFMTA/TIDA
Procurement	TIMMA	SFMTA/TIDA
Supply AVS (including all required systems)	Shuttle Vendor	
Testing	Shuttle Vendor	TIMMA/TIDA
AVS Operations	Shuttle Vendor	TIMMA/TIDA
AVS Maintenance	Shuttle Vendor	TIMMA/TIDA
AVS Operations Staff	Shuttle Vendor	
AVS Processes and Procedures	Shuttle Vendor	TIMMA, SFMTA, TIDA

Source: SFCTA

All the operational and support environment including equipment, facilities, computer hardware, software, personnel, operational procedures, maintenance, and disposal will be shuttle vendor's responsibility.

6 Operational Scenarios

This section presents scenarios that capture how the system serves the needs of users and protects all road users when the system is operating under various modes of operation. Each scenario lists objectives, users, flow of events, post-conditions, related policies and business rules, user needs traceability, and a summary of inputs and outputs. The preconditions describe the state of the environment at the onset of the scenario, and the events describe the various events that occur, and actions taken by users and the system. Various scenarios for each use case describe various modes of operations that are expected: normal operating conditions and degraded and/or failure conditions as necessary.

The operational scenarios are intended to depict generally expected scenarios that the AVS may encounter. The scenarios are not intended to be a comprehensive or complete list of possible scenarios.

Six use cases are described in this document:

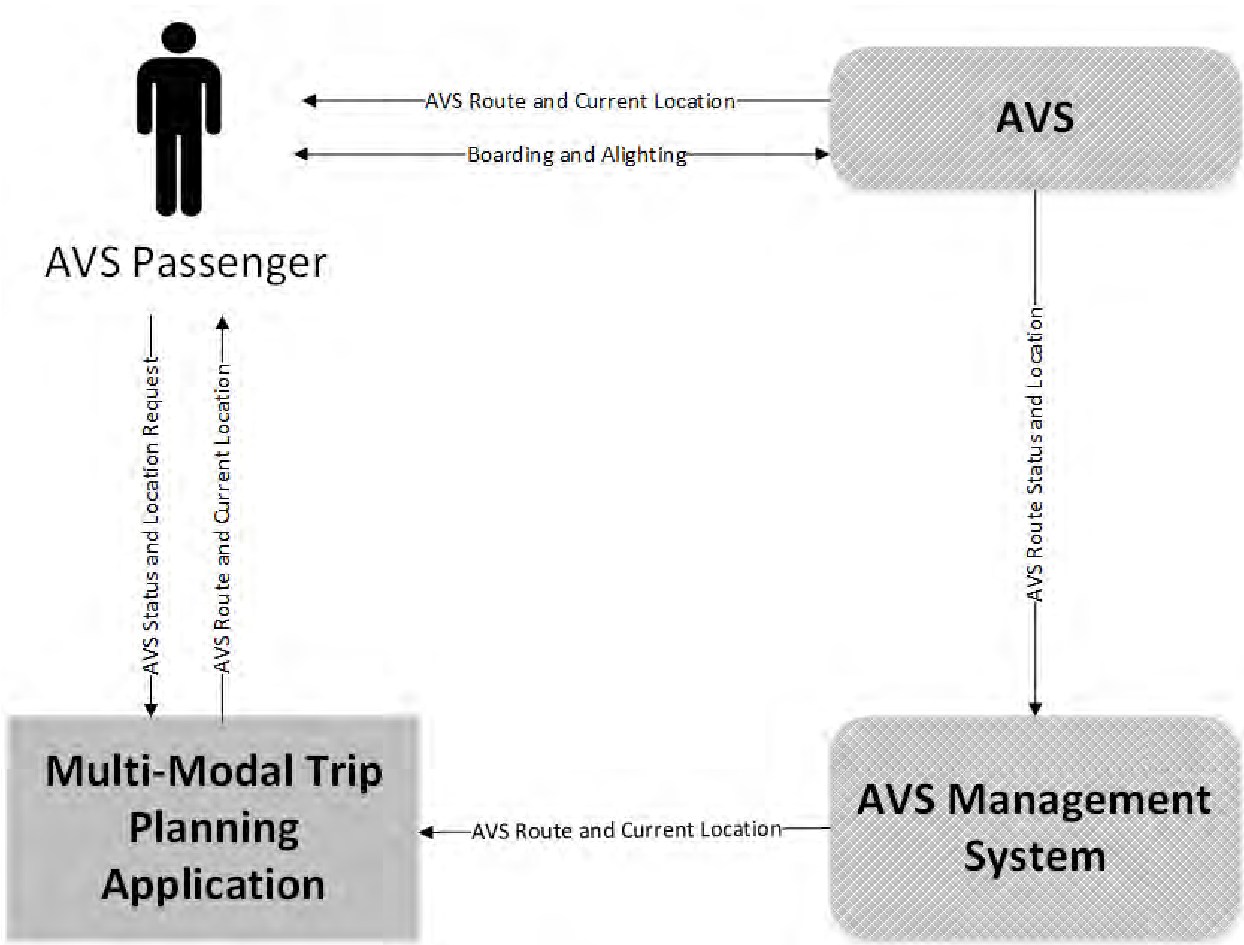
- Use Case 1: Taking an AVS Trip
- Use Case 2: Battery Energy Management and Recharging
- Use Case 3: Mixed Traffic Operations
- Use Case 4: Roadway Object Detection and Reaction
- Use Case 5: Crash Detection and Mitigation
- Use Case 6: AVS Operations Management

Note: During the pilot, the vehicle concierge or safety driver (human operator) will take the role of the Operations Staff and certain functions of the AVS Management System.

Some user needs are universal in nature and are not included in the scenarios for simplicity. Specifically, AVS-UN024-v01 (Operational Design Domain) is not included because the AVS needs to constantly monitor its environment to ensure it is operating in its intended operational design domain. As part of the RFP, the vendor will need to ensure that the operational design domain of their AVSs are compatible with the environment in which they will be operating on TI, including terrain, lighting, weather, and other operational design domain features. AVS-UN030-v01 (Data Transfer) in not included because the AVS and AVS Management System need to transfer data to enable most service functionality.

6.1 Use Case 1: Taking an AVS Trip

This section describes the scenario where a user takes an AVS trip.



(Multi-Modal Trip Planning Application is optional)

Source: SFCTA

Figure 2: Use Case 1: Taking an AVS Trip Diagram

Table 10: Use Case 1 Scenario 1: Normal Operating Conditions – Passenger Pick Up and Drop Off

Use Case	Taking an AVS Trip
Scenario ID & Title	*UC1-S1: Normal Operating Conditions - Passenger Pick Up and Drop Off*
Scenario Objective	• Provision of shuttle service using AVS to an AVS passenger
Operational Event(s)	• The AVS stops at an AVS shuttle stop (either by stopping at every stop or optionally on-demand), allows an AVS passenger to board the AVS, and proceeds along its route • The AVS passenger communicates to the AVS (possibly by push button) that he or she would like to alight at the next stop (optional) • The AVS stops at the next stop and the AVS passenger alights

Use Case	Taking an AVS Trip			
Actor(s)	Actor	Role		
	AVS Passenger	Board and alight AVS at the proper AVS shuttle stops		
	AVS	Stop to pick up passengers, stop to drop off passengers, wait for passengers to complete boarding and alighting before resuming along route, safely interact with traffic stream while pulling into and out of AVS shuttle stops		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS Passenger	1	Waiting at AVS Shuttle Stop 1	Possibly after having accessed AVS Trip Planning information, including route and schedule, via static roadside schedules or optionally real-time data on a mobile device or computer.
	AVS	2	Approaches AVS Shuttle Stop 1 and pulls into the stop area	On a bay or shoulder to the right of travel lanes. The AVS will stop at each stop for fixed-route operations or optionally be summoned for on-demand operations.
	AVS	3	Opens door	To allow AVS passenger to board and other passengers to alight
	AVS Passenger	4	Boards AVS	In case the passenger has a bicycle (or other equipment (wheelchair, walker, stroller, etc.), he or she loads into the AVS prior to boarding.
	AVS	4a	Counts boarding passengers	Counts passenger boarding the AVS using an APC or recorded by concierge.
	AVS	5	Closes door	After detecting that no additional passengers are still boarding or alighting or after a predetermined

Use Case	Taking an AVS Trip			
				interval with a sensor override
	AVS	6	Merges back into traffic stream	After detecting that it is safe to do so
	AVS	7	Continues along route	Stopping at every stop along the route (unless an optional boarding request system is added). This is also where other operational scenarios take place. AVS makes sound and emits lights to let others know of its presence. AVS also has a controlled climate within the vehicle.
	AVS	8	Makes an internal audio and visual display announcement to passengers that the AVS is approaching the next AVS shuttle stop	
	AVS	9	Approaches the next AVS shuttle stop and pulls into stop area (if there was another vehicle, AVS will wait for its turn at the curb).	
	AVS	10	Opens door	To allow AVS passenger to exit, and perhaps to allow other passengers to board
	AVS Passenger	11	Alights AVS	In case the passenger has a bicycle or other equipment (wheelchair, walker, stroller, etc.), he or she unloads into the AVS after alighting.
	AVS	11a	Counts alighting passengers	Counts passenger alighting the AVS using APC or recorded by concierge.
	AVS	12	Closes door	

Use Case	Taking an AVS Trip			
	AVS	13	Merges back into traffic stream	After detecting that it is safe to do so
	AVS	14	Continues along route	
Post-conditions	AVS passengers are transported from origin to destination AVS shuttle stop			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN001-v01 – Boarding AVS AVS-UN002-v01 – Alighting AVS AVS-UN003-v01 – Traveler Information AVS-UN005-v01 – Concierge AVS-UN007-v01 – Stop for Passenger Boarding AVS-UN008-v01 – Stop for Passenger Alighting AVS-UN009-v01 – Ridership Data AVS-UN011-v01 – Quiet Car Alert AVS-UN013-v01 – Transportation Management System AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN025-v01 – Climate Control AVS-UN038-v01 – Manual Data Collection			
Inputs Summary	System Initialization Input: AVS route set at time of configuration and advertised to potential passengers Human Inputs: Boarding and alighting requests (optional)			
Output Summary	AVS Data: Passenger counts, including number of bicycles, strollers, wheelchairs, and other equipment and number of users who couldn't board due to capacity; miles driven; dwell time at each stop Survey Data: Perceived personal safety and overall system safety when riding or encountering shuttle (to be collected by operations staff) Operations Data: Annualized operating expenses (to be collected by vendor and SFCTA)			

Source: SFCTA

Table 11: Use Case 1 Scenario 2: Normal Operating Conditions – Problem on Board

Use Case	Taking an AVS Trip
Scenario ID & Title	*UC1-S2: Normal Operating Conditions – Problem on Board*
Scenario Objective	• Provide an opportunity for AVS passengers to alert the AVS Management System if there is a problem on board the AVS *Note: This situation is applicable for a future scenario when there is no vehicle concierge on board. When the vehicle concierge is onboard, he/she will play the role of AVS Management System/Operations Staff.*

<table>
<tr><th>Use Case</th><th colspan="4">Taking an AVS Trip</th></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• While taking an AVS trip, an AVS passenger senses a problem on board
• The AVS passenger presses the safety alert button
• The AVS Management System is alerted and informs operations staff, who communicate with the AVS passenger, and decide how to intervene</td></tr>
<tr><td rowspan="4">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS Passenger</td><td colspan="3">Alert AVS Management System of problem onboard</td></tr>
<tr><td>AVS Management System</td><td colspan="3">Receive alert and relay to operations staff</td></tr>
<tr><td>Operations Staff</td><td colspan="3">Respond to AVS passenger, determine the extent of the problem, and respond appropriately</td></tr>
<tr><td rowspan="10">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS Passenger</td><td>1</td><td>Takes an AVS trip</td><td>Currently on board the AVS</td></tr>
<tr><td>AVS Passenger</td><td>2</td><td>Senses there is a problem on board</td><td>For example, crime or health issue for another passenger</td></tr>
<tr><td>AVS Passenger</td><td>3</td><td>Presses Passenger Alert Button</td><td>Installed onboard the AVSs</td></tr>
<tr><td>AVS Management System</td><td>4</td><td>Sees Passenger Alert Button was pressed, alerts operations staff</td><td></td></tr>
<tr><td>AVS</td><td>4a</td><td>The vehicle determines a safe and legal location to come to an immediate safe stop.</td><td></td></tr>
<tr><td>Operations Staff</td><td>5</td><td>Contacts AVS passenger</td><td>Perhaps through speakers on board AVS. Alternatively, AVS operator staff in the vehicle can assist the passenger.</td></tr>
<tr><td>Operations Staff</td><td>6</td><td>Reviews current and recent footage from security camera, if connectivity allows</td><td>To further assess the situation, video from the camera will be stored. Footage review could also take place after Step 8.</td></tr>
<tr><td>Operations Staff</td><td>7a</td><td>Realizes AVS passenger pressed button with a valid concern</td><td></td></tr>
<tr><td>Operations Staff</td><td>8a</td><td>Responds appropriately by contacting the relevant authorities or stepping in manually</td><td></td></tr>
</table>

Use Case	Taking an AVS Trip			
	Operations Staff	7b	Realizes AVS passenger pressed button by mistake or with an invalid concern (such as uneasiness with a safe function of the AVS)	
	Operations Staff	8b	Reassures passenger but does not step in or contact authorities	
Post-conditions	• Operations staff can step in and resolve the situation the AVS passenger is sensing on board the AVS			
Policies and Business Rules	SFCTA Video Retention Policy. While AVS is in operation, Management staff to be on-call and operations staff on the island.			
User Needs Traceability	AVS-UN004-v01 – Passenger Safety Alert AVS-UN005-v01 – Concierge AVS-UN014-v01 – Security Camera AVS-UN022-v01 – Disengagement Mechanism			
Inputs Summary	System Initialization Input: Program Passenger Alert Button to contact the AVS Management System when pressed Human Inputs: Communication between AVS passenger and operations staff			
Output Summary	AVS Data: Record that operations staff may have had to intervene (Disengagement data with timestamp, location, and cause); scheduled hours of operation; actual hours of operation			

Source: SFCTA

Table 12: Use Case 1 Scenario 3: Normal Operating Conditions – ADA Accessibility

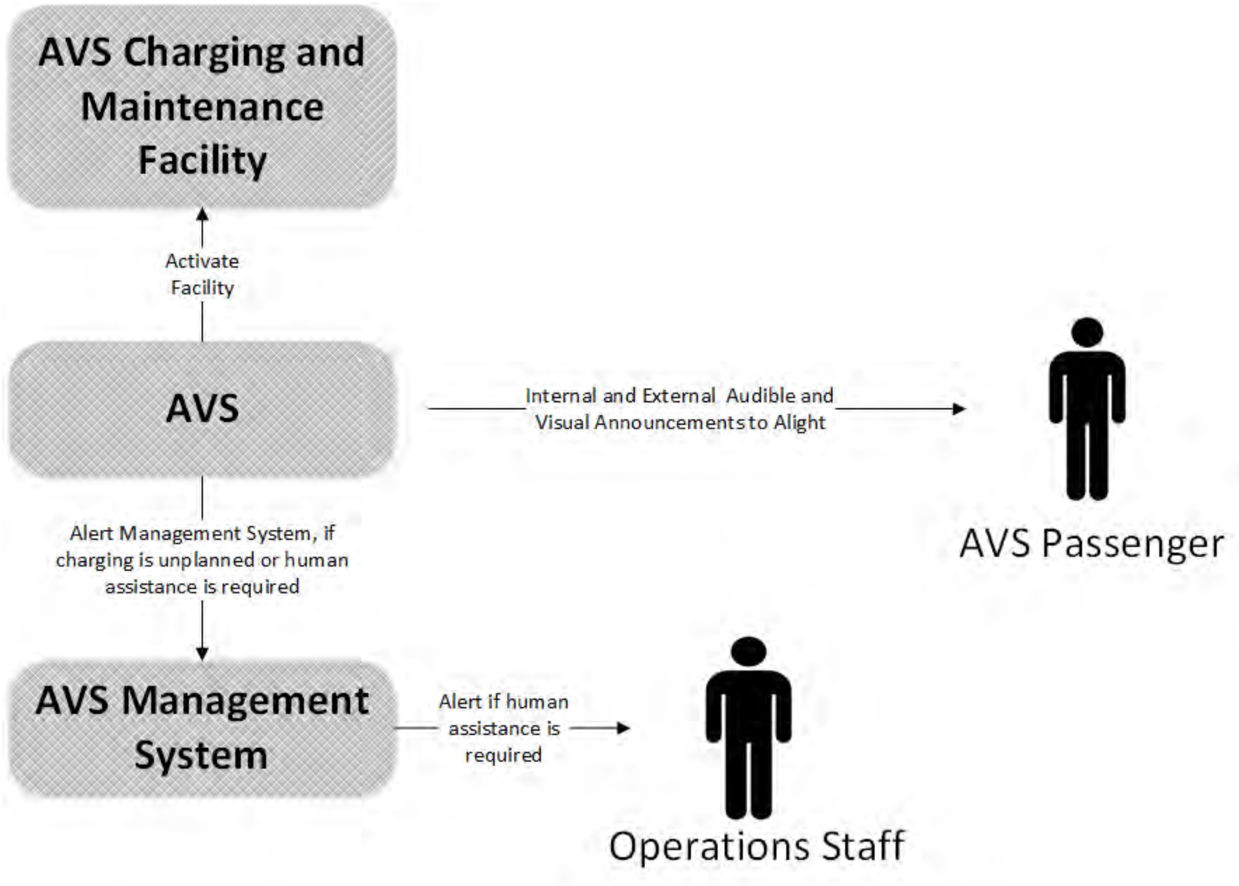
<table>
<tr><th>Use Case</th><th colspan="4">Taking an AVS Trip</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC1-S3: Normal Operating Conditions – ADA Accessibility</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Allow an AVS passenger in a wheelchair or with limited mobility to communicate to the AVS that it should provide assistance so he or she can board and alight more easily</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS stops at an AVS shuttle stop, and a boarding AVS passenger requests ADA assistance. The AVS provides assistance and the AVS passenger boards.
• The AVS continues its route
• The AVS passenger communicates to the AVS that he or she would like to alight at the next stop and requests ADA assistance. The AVS stops at the next stop, provides assistance, and the AVS passenger alights.</td></tr>
<tr><td rowspan="3">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS Passenger</td><td colspan="3">Board and alight the AVS</td></tr>
<tr><td>AVS</td><td colspan="3">Allow passengers with limited mobility to board and alight the AVS</td></tr>
<tr><td rowspan="10">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Arrives at stop and opens door</td><td></td></tr>
<tr><td>AVS Passenger</td><td>2</td><td>Communicates to AVS that it should provide ADA assistance</td><td>Likely with a button near the door of the AVS or with a verbal command</td></tr>
<tr><td>AVS</td><td>3</td><td>Provides assistance</td><td>Perhaps by lowering a ramp or “kneeling”, if required, and providing audible guidance.</td></tr>
<tr><td>AVS Passenger</td><td>4</td><td>Boards AVS</td><td>The passenger or concierge secures the wheelchair as applicable and verifies that the passenger is secure.</td></tr>
<tr><td>AVS</td><td>5</td><td>Resets AVS</td><td>For example, by retracting ramp</td></tr>
<tr><td>AVS</td><td>6</td><td>Closes door</td><td></td></tr>
<tr><td>AVS</td><td>7</td><td>Merges back into traffic stream</td><td>After detecting that it is safe to do so</td></tr>
<tr><td>AVS Passenger</td><td>8</td><td>Indicates when AVS is approaching stop he/she would like to get off at, and requests ADA assistance</td><td></td></tr>
<tr><td>AVS</td><td>9</td><td>Arrives at stop, opens door, and provides ADA assistance</td><td></td></tr>
</table>

<table>
<tr><th>Use Case</th><th colspan="4">Taking an AVS Trip</th></tr>
<tr><td></td><td>AVS Passenger</td><td>10</td><td>Alights AVS</td><td></td></tr>
<tr><td>Post-conditions</td><td colspan="4">• AVS passenger could board and alight the AVS and has been transported to their intended destination</td></tr>
<tr><td>Policies and Business Rules</td><td colspan="4">None</td></tr>
<tr><td>User Needs Traceability</td><td colspan="4">AVS-UN006-v01 – ADA Accessibility
AVS-UN010-v01 – ADA Accessibility
AVS-UN036-v01 – Assistance for People with Disabilities</td></tr>
<tr><td>Inputs Summary</td><td colspan="4">System Initialization Input: ADA assistance request capability will need to be set up for boarding and alighting passengers
Human Inputs: None (may be needed during the pilot depending on pilot capabilities)</td></tr>
<tr><td>Output Summary</td><td colspan="4">AVS Data: Passenger counts, including how many passengers requested ADA assistance and how many disabled passengers could board and be secured without assistance</td></tr>
</table>

Source: SFCTA

6.2 Use Case 2: Battery Energy Management and Recharging

This section describes scenarios concerning AVS charging and battery management.



Source: SFCTA

Figure 3: Use Case 2: Battery Energy Management and Recharging Diagram

Table 13: Use Case 2 Scenario 1: Normal Operating Conditions – Manual/Automated End of Route Recharging

<table>
<tr><th>Use Case</th><th colspan="4">Battery Energy Management and Recharging</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC2-S1: Normal Operating Conditions – Manual/Automated End of Route Recharging</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Automatically recharge the AVS battery at the end of a route (nearest storage area or charging station) at the end of service
Note: This Use Case assumes that the vehicle will be battery-powered and will require periodic recharging</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS arrives at the stop in its route closest to the charging facility and determines if scheduled charging will be required the next time it reaches this stop
• The AVS completes a full loop of its route with an alert (through audio and updates on screen monitor) to AVS passengers that it will be taken out of service for charging at that stop
• The AVS arrives at that stop and determines if all passengers have exited the AVS
• The AVS travels to the storage area for recharging</td></tr>
<tr><td rowspan="3">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Navigate to charging area when necessary</td></tr>
<tr><td>AVS Passenger 1,
AVS Passenger 2</td><td colspan="3">Exit the AVS at or before the end of AVS service</td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Approaches AVS Shuttle Stop 1, the stop of the AVS route closest to the charging facility</td><td>May also be the final stop of the route</td></tr>
<tr><td>AVS</td><td>2</td><td>Determines that the AVS is approaching the end of its service period and that the next service loop will be its last for the day</td><td></td></tr>
<tr><td>AVS</td><td>3</td><td>Changes external electronic sign to indicate that the AVS will return to the charging station at the beginning of the loop, and produces an internal audible announcement at every stop that the vehicle will only travel as far as AVS Shuttle Stop 1</td><td></td></tr>
<tr><td>AVS</td><td>4</td><td>Continues along route</td><td></td></tr>
<tr><td>AVS</td><td>5</td><td>Arrives at AVS Shuttle Stop 1</td><td></td></tr>
<tr><td>AVS</td><td>6</td><td>Makes an external audio announcement to waiting passengers not to board the AVS</td><td></td></tr>
</table>

Use Case	Battery Energy Management and Recharging			
	AVS	7	Opens door to allow passengers to alight	
	AVS Passenger 1	8	Alights the AVS	
	AVS Passenger 2	9	Boards the AVS	
	AVS	10	Uses internal sensors to detect if there are no AVS passengers remaining	Detects that AVS passenger 2 is still on the AVS
	AVS	11	Waits with door open, and makes an internal and external audio announcement to passengers that all passengers must exit the AVS	
	AVS Passenger 2	12	Alights the AVS	Could board next AVS
	AVS	13	Returns to charging facility	May also be maintenance facility and storage space
	AVS	14	Navigates to the manual/automatic charging point	
	AVS	15a	Remains connected to manual/automatic charger until beginning of the next service period	
	AVS	15b	Remains connected to manual/automatic charger until it has enough energy to complete the remainder of service period	
	AVS	16	Leaves the charging facility and travels to AVS Shuttle Stop 1	Normal service resumes
Post-conditions	• AVS has enough energy to complete its next loop, minimizing service disruptions			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN012-v01 – Manual Fueling AVS-UN028-v01 – End of Service Period AVS-UN031-v01 – AVS Charge AVS-UN033-v01 – Managed AVS Charging			
Inputs Summary	System Initialization Input: reserve energy required to allow AVS to start and complete a new route Human Input: None			
Output Summary	AVS Data: record of charging time; scheduled hours of operation			

Source: SFCTA

Table 14: Use Case 2 Scenario 2: Degraded Conditions –Automated End of Route Recharging

<table>
<tr><th>Use Case</th><th colspan="4">Battery Energy Management and Recharging</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC2-S2: Degraded Conditions – Automated End of Route Recharging</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Automatically recharge the AVS battery at the end of a route (nearest storage area or charging station) when current battery level will not allow AVS to complete the next route
Note: This Use Case assumes that the vehicle will be battery-powered and will require periodic recharging</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS arrives at the stop in its route closest to the charging facility and determines if charging will be required the next time it reaches this stop
• The AVS completes a full loop of its route with an alert (through audio and updates on screen monitor) to AVS passengers that it will be taken out of service for charging at that stop
• The AVS arrives at that stop and determines if all passengers have exited the AVS
• The AVS travels to the storage area for recharging</td></tr>
<tr><td rowspan="3">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS 1, AVS 2</td><td colspan="3">Navigate to charging area when necessary, even if unscheduled</td></tr>
<tr><td>AVS Passenger 1,
AVS Passenger 2</td><td colspan="3">Exit the AVS at or before the end of AVS service</td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS 1</td><td>1</td><td>Approaches AVS Shuttle Stop 1, the stop of the AVS route closest to the charging facility</td><td>May also be the final stop of the route</td></tr>
<tr><td>AVS 1</td><td>2</td><td>Determines that the AVS does not have enough of a charge to complete another loop after the loop it is about to begin</td><td>Charge must also include reserve</td></tr>
<tr><td>AVS 1</td><td>3</td><td>Changes external electronic sign to indicate that the AVS will return to the charging station at the beginning of the loop, and produces an internal audible announcement at every stop that the vehicle will only travel as far as AVS Shuttle Stop 1</td><td></td></tr>
<tr><td>AVS 1</td><td>4</td><td>Continues along route</td><td></td></tr>
<tr><td>AVS 1</td><td>5</td><td>Arrives at AVS Shuttle Stop 1</td><td></td></tr>
<tr><td>AVS 1</td><td>6</td><td>Makes an external audio announcement to waiting passengers not to board the AVS</td><td></td></tr>
</table>

Use Case	Battery Energy Management and Recharging			
	AVS 1	7	Opens door to allow passengers to alight	
	AVS Passenger 1	8	Alights the AVS	
	AVS Passenger 2	9	Boards the AVS	
	AVS 1	10	Uses internal sensors to detect if there are no AVS passengers remaining	Detects that AVS Passenger 2 is still on the AVS
	AVS 1	11	Waits with door open, and makes an internal and external audio announcement to passengers that all passengers must exit the AVS	
	AVS Passenger 2	12	Alights the AVS	Could board next AVS
	AVS 1	13	Returns to charging facility	May also be maintenance facility and storage space
	AVS 1	14	Navigates to the automatic charging point	
	AVS 1	15	Remains connected to automatic charger until beginning of the next service period	
	AVS 2	15a	Leaves the charging facility and travels to AVS Shuttle Stop 1	Normal service resumes
Post-conditions	• AVS has enough energy to complete its next loop, minimizing service disruptions			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN012-v01 – Manual Fueling AVS-UN028-v01 – End of Service Period AVS-UN031-v01 – AVS Charge AVS-UN033-v01 – Managed AVS Charging			
Inputs Summary	System Initialization Input: reserve energy required to allow AVS to start and complete a new route Human Input: None			
Output Summary	Message from AVS to AVS Management System if unplanned charging event will occur AVS Data: record of unplanned charging events, calculation of vehicle efficiency to help prevent future unplanned charging events; scheduled hours of operation; actual hours of operation			

Source: SFCTA

Table 15: Use Case 2 Scenario 3: Degraded Conditions – Manual End of Route Recharging

<table>
<tr><th>Use Case</th><th colspan="4">Battery Energy Management and Recharging</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC2-S3: Degraded Conditions – Manual End of Route Recharging</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Manually recharge the AVS battery when automatic charging capability is not possible
Note: This Use Case assumes that the AVS will be battery-powered and will require periodic recharging</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• Malfunctioning automatic charger
• This scenario replaces Steps 15-16 in the fully operational scenario for this use case</td></tr>
<tr><td rowspan="4">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Successfully connect to a charger, even if it requires human assistance</td></tr>
<tr><td>AVS Management System</td><td colspan="3">Manage the charging of the AVSs</td></tr>
<tr><td>Operations Staff</td><td colspan="3">Assist with manual fueling of the AVSs</td></tr>
<tr><td rowspan="10">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Detects that automatic charger is not active (or the feature is unavailable)</td><td></td></tr>
<tr><td>AVS</td><td>2</td><td>Notifies the AVS Management System that automatic charging is not working</td><td></td></tr>
<tr><td>AVS Management System</td><td>3</td><td>Assigns operations staff to manually attend to the AVS</td><td></td></tr>
<tr><td>Operations Staff</td><td>4</td><td>Manually plugs in the AVS</td><td></td></tr>
<tr><td>AVS</td><td>5a</td><td>Detects that battery charge is sufficient to continue operations</td><td></td></tr>
<tr><td>AVS</td><td>5b</td><td>Detects that the battery is fully charged</td><td></td></tr>
<tr><td>AVS</td><td>6</td><td>Notifies the AVS Management System to unplug the AVS</td><td>So that it can continue service</td></tr>
<tr><td>AVS Management System</td><td>7</td><td>Assigns operations staff to manually attend to the AVS</td><td></td></tr>
</table>

Use Case	Battery Energy Management and Recharging			
	Operations Staff	8	Manually unplugs the AVS	
	AVS	9	Detects that it is no longer plugged in	
	AVS	10	Leaves the charging facility and travels to the first stop along the route	Normal service resumes
Post-conditions	• AVS has enough energy to complete its next route, minimizing service disruptions			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN012-v01 – Manual Fueling AVS-UN031-v01 – AVS Charge AVS-UN033-v01 – Managed AVS Charging			
Inputs Summary	*Same as Inputs for Normal Operating Conditions scenario*			
Output Summary	Message from AVS to AVS Management System for manual charging assistance AVS Data: record of automatic charger downtime; scheduled hours of operation; actual hours of operation			

Source: SFCTA

Table 16: Use Case 2 Scenario 4: Degraded Conditions – Inadequate Battery Energy During Service

Use Case	Battery Energy Management and Recharging	
Scenario ID & Title	*UC2-S4: Degraded Conditions – Inadequate Battery Energy During Service*	
Scenario Objective	• Demonstrate ability of AVS to navigate to a safe location to await operations staff assistance when in the middle of a route and current battery level will not allow AVS to complete route *Note: This Use Case assumes that the AVS will be battery-powered and will require periodic recharging. This scenario is also applicable for any other maintenance issues.*	
Operational Event(s)	• AVS does not have enough charge to complete its route and must navigate to a safe location and await assistance	
Actor(s)	Actor	Role
	AVS Passenger	Not get stranded on an AVS that is not able to complete route due to a drained battery, especially in an unsafe area, such as the roadway
	AVS	Navigate to safe area when necessary

Use Case	Battery Energy Management and Recharging			
	AVS Management System	Assign operations staff to provide response to AVS when necessary		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS	1	Is in the middle of the AVS route	
	AVS	2	Detects that it will not be able to complete its current loop with the current energy level	
	AVS	3	Notifies the AVS Management System that the AVS will not be able to reach the end of this route loop	Alternatively, operations staff could make this determination
	AVS	4	Makes an internal audio announcement to passengers that all passengers must exit the AVS at the next stop due to a maintenance issue	
	AVS	5	Arrives at the next AVS shuttle stop	
	AVS	6	Opens door to allow passengers to alight	
	AVS Passenger	7	Alight the AVS	May wait for next AVS or walk to destination
	AVS	8	Uses internal sensors to detect if there are no AVS passengers remaining	No passengers remain
	AVS	9	Closes door	If possible, so that no other passengers can board
	AVS	10a	Remains at this AVS shuttle stop	If this AVS shuttle stop is not in a lane of travel
	AVS	10b	Moves from the AVS shuttle stop to the next-available roadway shoulder	If this AVS shuttle stop is in a lane of travel, and shoulder is available. Operations staff could alternatively do this.

Use Case	Battery Energy Management and Recharging			
	AVS	10c	Moves from the AVS shuttle stop into the next parking lot to park	If this AVS shuttle stop is in a lane of travel, and no shoulder is available, or a parking lot is closer. Operations staff could alternatively do this.
	AVS Management System	11	Assigns operations staff to provide a response to the AVS	
Post-conditions	• AVS passenger is safely able to exit the AVS and informed of options to complete trip • The AVS Management System is notified of the low/empty battery or other maintenance issues and provides an appropriate response to get the AVS fit for normal operating mode			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN033-v01 – Managed AVS Charging			
Inputs Summary	*Same as Inputs for Normal Operating Conditions scenario*			
Output Summary	Message from AVS to AVS Management System of the stop location of the disabled AVS AVS Data: record of unplanned charging incident; scheduled hours of operation; actual hours of operation			

Source: SFCTA

Table 17: Use Case 2 Scenario 5: Failure Conditions – Loss of Battery Energy During Service

Use Case	Battery Energy Management and Recharging
Scenario ID & Title	*UC2-S5: Failure Conditions – Loss of Battery Energy During Service*
Scenario Objective	• Coming to a safe stop in an unsafe environment due to a complete loss of power *Note: This Use Case assumes that the AVS will be battery-powered and will require periodic recharging. This scenario is also applicable for any other maintenance issues.*

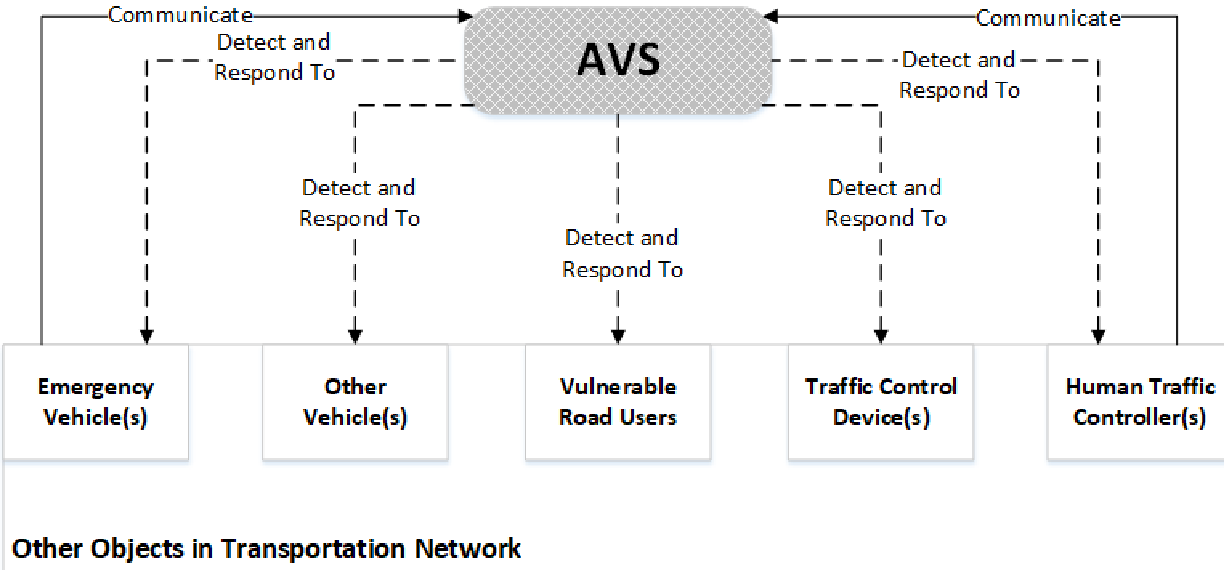
<table>
<tr><th>Use Case</th><th colspan="4">Battery Energy Management and Recharging</th></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• AVS needs to come to a safe stop due to loss of battery charge while en-route or any other maintenance issues.</td></tr>
<tr><td rowspan="4">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS Passenger</td><td colspan="3">Not get stranded on an AVS that is not able to complete route due to a drained battery, especially in an unsafe area, such as the roadway</td></tr>
<tr><td>AVS</td><td colspan="3">Navigate to charging area when necessary</td></tr>
<tr><td>AVS Management System</td><td colspan="3">Manage the energy of batteries on all AVSs</td></tr>
<tr><td rowspan="11">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Is in the middle of the AVS route</td><td></td></tr>
<tr><td>AVS</td><td>2</td><td>Loses primary power</td><td></td></tr>
<tr><td>AVS</td><td>3</td><td>Comes to an immediate stop, ideally by pulling over to the side of the road</td><td>Switches to secondary backup power</td></tr>
<tr><td>AVS</td><td>4</td><td>Notifies the AVS Management System that the AVS will not be able to reach the end of this route loop</td><td>Using secondary backup power</td></tr>
<tr><td>AVS</td><td>5</td><td>Makes an internal audio announcement to passengers that all passengers must exit the AVS due to a maintenance issue</td><td>Using secondary backup power</td></tr>
<tr><td>AVS</td><td>6a</td><td>Opens door to allow passengers to alight</td><td>Using secondary backup power</td></tr>
<tr><td>AVS Passenger</td><td>6b</td><td>Force door open</td><td>If no secondary backup power remains</td></tr>
<tr><td>AVS Passenger</td><td>7</td><td>Alight the AVS</td><td>May wait for next AVS or walk to destination</td></tr>
<tr><td>AVS Management System</td><td>8</td><td>Provides a response to the AVS</td><td></td></tr>
<tr><td>Post-conditions</td><td colspan="4">• AVS passenger must safely exit the AVS
• The AVS stops in a location where it impedes traffic flow and may cause a hazard for other road users
• The AVS Management System is notified of the loss of battery power and provides an appropriate response to get the AVS recharged and back to a normal operating mode.
• San Francisco Police Department is notified by AVS Management System. Law enforcement officials may need to be involved to direct other traffic around disabled AVS.</td></tr>
</table>

Use Case	Battery Energy Management and Recharging
Policies and Business Rules	*None*
User Needs Traceability	AVS-UN033-v01 – Managed AVS Charging
Inputs Summary	*Same as Inputs for Normal Operating Conditions scenario*
Output Summary	Message from AVS to AVS Management System of the location of the disabled AVS AVS Data: record of unplanned incident on the roadway; scheduled hours of operation; actual hours of operation

Source: SFCTA

6.3 Use Case 3: Mixed Traffic Operations

This section describes scenarios where an AVS operates safely in mixed traffic, obeying all applicable laws and regulations.



Source: SFCTA

Figure 4: Use Case 3: Mixed Traffic Operations Diagram

Table 18: Use Case 3 Scenario 1: Normal Operating Conditions – Intersection Navigation

<table>
<tr><th>Use Case</th><th colspan="4">Mixed Traffic Operations</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC3-S1: Normal Operating Conditions - Intersection Navigation</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate ability of the AVS to detect intersection type, traffic conditions, all roadway users, assess right-of-way, and complete a movement through an intersection along the direction of the route</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• AVS approaches an intersection and navigates through safely</td></tr>
<tr><td rowspan="2">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Safely navigate an intersection</td></tr>
<tr><td rowspan="5">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Approaches intersection</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>AVS</td><td>2a</td><td>Detects that the AVS is on an uncontrolled approach</td><td></td></tr>
<tr><td>AVS</td><td>3a</td><td>Detects whether other intersection approaches are uncontrolled or</td><td></td></tr>
</table>

Use Case	Mixed Traffic Operations			
			stop-controlled, detects if there are any other road users at the intersection, and makes appropriate right-of-way decisions	
	AVS	4a	Safely proceeds through the intersection and continues its route	
	AVS	2b	Detects that the AVS is on a stop-controlled approach	
	AVS	3b	Detects whether other intersection approaches are uncontrolled or stop-controlled, detects if there are any other road users at the intersection, and makes appropriate right-of-way decisions	
	AVS	4b	Safely proceeds through the intersection and continues its route	
Post-conditions	• The AVS proceeds safely through the intersection and continues its route			
Policies and Business Rules	California Vehicle Code			
User Needs Traceability	AVS-UN015-v01 – Law-Following – Open Traffic Environment AVS-UN016-v01 – Law Following – Regulatory			
Inputs Summary	System Initialization Input: Right-of-way rules and hierarchy to be programmed into AVS in compliance with US laws, regulations, and normal travel behavior Human Input: None			
Output Summary	AVS Data: Record of decisions made, record of accurate object classification and path prediction			

Source: SFCTA

Table 19: Use Case 3 Scenario 2: Degraded Conditions – Intersection Navigation – Malfunctioning Sensor

Use Case	Mixed Traffic Operations
Scenario ID & Title	*UC3-S2: Degraded Conditions – Intersection Navigation – Malfunctioning Sensor*
Scenario Objective	• Demonstrate fall back condition should the AVS have a malfunctioning sensor diminishing its ability to detect objects

Operational Event(s)	• AVS approaches an intersection with a malfunctioning sensor			
Actor(s)	**Actor**	**Role**		
	AVS	Safely navigate an intersection		
	Other Vehicle	Safely navigate an intersection		
Key Actions and Flow of Events	**Actor**	**Step**	**Key Action**	**Comments**
	AVS	1	Approaches intersection	
	AVS	2	Detects that its sensor is malfunctioning.	
	AVS	3	Comes to a safe stop at next legal and safe location. (AVS may use the secondary sensor to navigate to the safe stop)	
	AVS	4	Alerts AVS Management System and passengers to potential issue and wait for further instructions	
	AVS	5	Prior to coming to safe stop, if it senses potential crash, reacts appropriately to avoid or minimize human injuries	
Post-conditions	• The AVS Management System is notified of the issue and holds the AVS at a stop until the sensor can be fixed			
Policies and Business Rules	California Vehicle Code Division 11 Chapter 2 – Traffic Signs, Signals, and Markings			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN019-v01 – Crash Avoidance			
Inputs Summary	System Initialization Input: Right-of-way rules and response algorithm to be programmed into AVS in compliance with US laws, regulations, and normal travel behavior Human Input: None			
Output Summary	AVS Data: Record of decisions made, record of reason for malfunction, record of stop location and decision process for location choice			

Source: SFCTA

Table 20: Use Case 3 Scenario 3: Normal Operating Conditions – Regulatory and Warning Signs and Pavement Markings

Use Case	Mixed Traffic Operations
Scenario ID & Title	*UC3-S3: Normal Operating Conditions – Regulatory and Warning Signs and Pavement Markings*
Scenario Objective	• Demonstrate ability of the AVS to detect and properly interpret traffic control devices specified in the MUTCD

Use Case	Mixed Traffic Operations			
Operational Event(s)	• The AVS detects and correctly responds to roadway signage, including regulatory and warning signs, pavement markings, and temporary traffic control devices			
Actor(s)	Actor	Role		
	AVS	Detect signs, pavement markings, and temporary traffic control devices, adjust driving behavior accordingly		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS	1a	Detects a regulatory sign	
	AVS	2a	Comprehends sign information	
	AVS	3a	Uses information to understand what it must or should do (or not do) under a given set of circumstances	
	AVS	1b	Detects a warning sign	
	AVS	2b	Comprehends sign information	
	AVS	3b	Uses information to understand conditions that might call for a reduction of speed or an action in the interest of safety and efficient traffic operations	
	AVS	1c	Detects a pavement marking	
	AVS	2c	Comprehends pavement marking information	
	AVS	3c	Uses information to understand pavement and curb boundaries, boundary types, regulation, guidance, and warnings	
	AVS	1d	Detects a temporary traffic control device	
	AVS	2d	Comprehends temporary traffic control device information	
	AVS	3d	Uses information to understand what it must or should do (or not do) under a given set of circumstances	
Post-conditions	• The AVS continues its route in a lawful manner			
Policies and Business Rules	https://mutcd.fhwa.dot.gov/kno_2009r1r2.htm *MUTCD Part 2 - Signs -* https://mutcd.fhwa.dot.gov/htm/2009r1r2/part2/part2_toc.htm *MUTCD Part 3 - Markings -* https://mutcd.fhwa.dot.gov/htm/2009r1r2/part3/part3_toc.htm *MUTCD Part 6 - Temporary Traffic Control -* https://mutcd.fhwa.dot.gov/htm/2009r1r2/part6/part6_toc.htm			

Use Case	Mixed Traffic Operations
User Needs Traceability	AVS-UN016-v01 – Law Following – Regulatory AVS-UN017-v01 – Law Following – Temporary Traffic Control
Inputs Summary	System Initialization Input: Local rules, regulations, and standard signage must be programmed into the AVS at time of configuration Human Input: None
Output Summary	AVS Data: Record of objects detected and appropriately classified, record of decisions made and record of instances when the vehicle did not comply with traffic regulations.

Source: SFCTA

Table 21: Use Case 3 Scenario 4: Degraded Conditions – Uncertainty in Course of Action

<table>
<tr><th>Use Case</th><th colspan="4">Mixed Traffic Operations</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC3-S6: Degraded Conditions – Uncertainty in Course of Action</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate ability of the AVS to exercise caution when there is uncertainty in the detection or interpretation of a traffic control device</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS encounters a situation it does not understand and alerts the AVS Management System to determine whether the situation is unusual and something the AVS has not been programmed to understand or whether there is a maintenance issue with the AVS. The AVS Management System and operations staff can then work to fix the AVS or program in additional scenarios to avoid the same situation in the future.</td></tr>
<tr><td rowspan="4">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Safely navigate roadways and understand when it is not fully able to operate normally, alert AVS Management System and move to fall back state in the event of abnormal conditions</td></tr>
<tr><td>AVS Management System</td><td colspan="3">Respond to messages from AVS and understand issues AVS is having, and assign operations staff to fix any problems (or suspend service until problems can be fixed)</td></tr>
<tr><td>Operations Staff</td><td colspan="3">Provide repairs or solve other problems</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Detects traffic control device</td><td>Such as a human controlling traffic or a regulatory sign</td></tr>
<tr><td>AVS</td><td>2</td><td>Is not certain of its interpretation of this traffic control device</td><td></td></tr>
<tr><td>AVS</td><td>3</td><td>Decreases speed</td><td>To properly interpret traffic control device</td></tr>
</table>

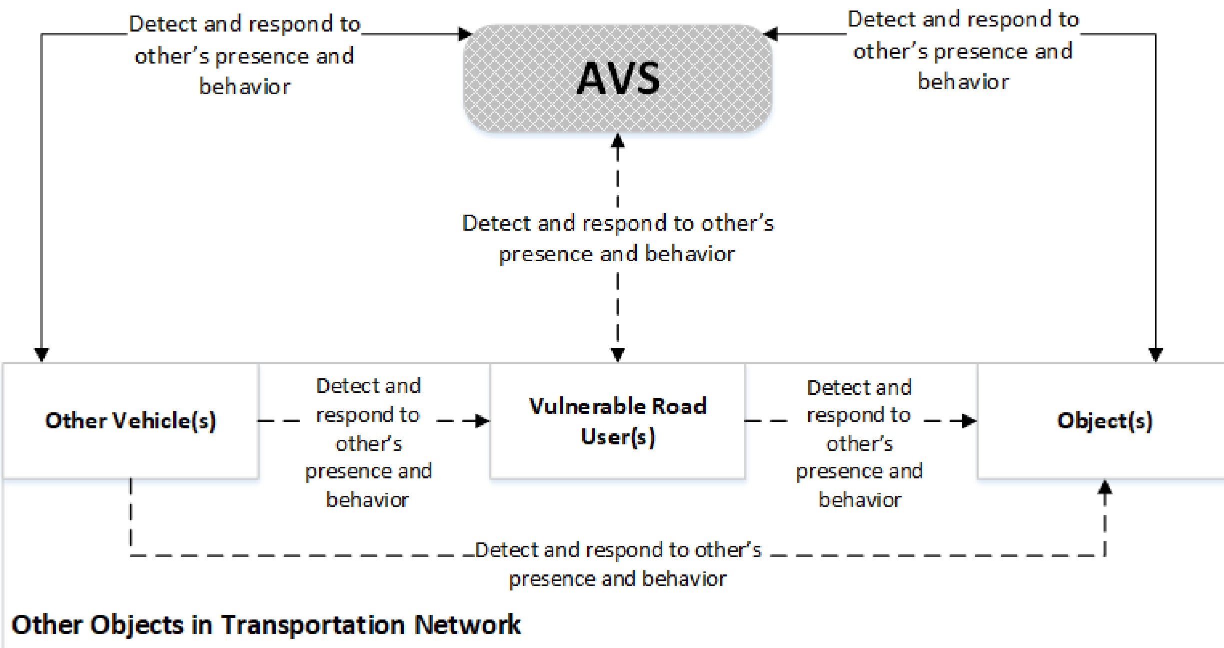
Use Case	Mixed Traffic Operations			
	AVS	4	Notifies AVS Management System that it has encountered an issue	
	AVS	5a	Resumes certain interpretation of traffic control devices	
	AVS	6a	Continues along route at nominal speed	
	AVS	5b	Continues to not be certain of its interpretation of traffic control devices	
	AVS	6b	Comes to a complete stop and notifies passengers of the issue	
	AVS Management System	7b	Dispatches operations staff to repair sensors and/or manually navigate around the object	
	AVS	8b	Attempts to navigate to an off-street location to wait for operations staff	If navigation allows
	Operations Staff	9b	Repairs sensors	Could include external maintenance entity, or operations staff who manually operates AVS if repair effort is unsuccessful or will require additional resources
	AVS	10b	Continues along route	
Post-conditions	• AVS safely avoided an incident by returning to its fall back condition until issues could be resolved. Issues are now resolved and the AVS can return to normal operations.			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN020-v01 – Fall Back AVS-UN023-v01 – Uncertainty in Course of Action			
Inputs Summary	System Initialization Input: Fall back response must be programmed into AVS at time of configuration Human Input: Operations staff must intervene and work to determine the			

Use Case	Mixed Traffic Operations
	cause of the error to resolve and allow the AVS to return to autonomous operations
Output Summary	AVS Data: Record of incident and AVS's response

Source: SFCTA

6.4 Use Case 4: Roadway Object Detection and Reaction

This section describes a scenario where the AVS detects other objects on the roadway.



Source: SFCTA

Figure 5: Use Case 4: Roadway Object Detection and Reaction Diagram

Table 22: Use Case 4 Scenario 1: Normal Operating Conditions – Vehicle Following

Use Case	Roadway Object Detection and Reaction			
Scenario ID & Title	*UC4-S1: Normal Operating Conditions - Vehicle Following*			
Scenario Objective	• Demonstrate the ability of an AVS to safely operate in mixed traffic			
Operational Event(s)	• The AVS approaches another vehicle from behind, and must adjust its speed to remain at a safe following distance • Another driver changes lanes in front of the AVS, resulting in an unsafe following distance. The AVS must slightly slow down and speed back up to maintain a safe following distance.			
Actor(s)	Actor	Role		
	AVS	Follow vehicles at a minimum following distance, based on the speed of the leading vehicle and the AVS		
	Other Vehicle 1	Safely navigate roadway network		
	Other Vehicle 2	Safely navigate roadway network		
	Actor	Step	Key Action	Comments

Use Case	Roadway Object Detection and Reaction			
Key Actions and Flow of Events	AVS	1	Approaches Other Vehicle 1 from behind	AVS is traveling faster than Other Vehicle 1, but still below the speed limit
	AVS	2	Detects Other Vehicle 1 and the speed of Other Vehicle 1	
	AVS	3	Decreases speed to match the speed of Other Vehicle 1	In a manner, such that the AVS matches Other Vehicle 1's speed once it reaches the following distance corresponding to Other Vehicle 1's speed
	Other Vehicle 2	4	Changes lanes into the space between the AVS and Other Vehicle 1	Resulting in the AVS following distance to be too close.
	AVS	5	Slightly decreases speed	To increase following distance
	AVS	6	Changes speed to match Other Vehicle 2	Once it reaches a following distance corresponding to Other Vehicle 2's speed
	Other Vehicle 2	7	Increases/decreases speed	
	AVS	8	Continues to match the speed of Other Vehicle 2 at the specified following distance	
Post-conditions	• AVS, Other Vehicle 1, and Other Vehicle 2 all continue down the roadway at a safe following distance apart			
Policies and Business Rules	California Vehicle Code Division 11 Chapter 3 Article 2 – Additional Driving Rules			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment			
Inputs Summary	System Initialization Input: AVS needs to be programed with the safe following distances for each operating speed Human Input: None			
Output Summary	AVS Data: Record of following distances kept, video footage, and decisions made			

Source: SFCTA

Table 23: Use Case 4 Scenario 2: Normal Operating Conditions – Bicycle Following and Passing

<table>
<tr><th>Use Case</th><th colspan="4">Roadway Object Detection and Reaction</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC4-S2: Normal Operating Conditions – Bicycle/Pedestrian Following and Passing</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the ability of an AVS to safely follow a bicyclist/pedestrian and pass the bicyclist/pedestrian if conditions allow</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS approaches a bicyclist/pedestrian from behind, and must adjust its speed to remain at a safe following distance
• The AVS determines if it is safe to pass the bicyclist/pedestrian, and passes if able</td></tr>
<tr><td rowspan="4">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Detect bicyclist in roadway, follow bicyclist at safe following distance, pass bicyclist if it is safe to do so</td></tr>
<tr><td>Bicyclist</td><td colspan="3">Safely navigate roadway network</td></tr>
<tr><td>Other Vehicle</td><td colspan="3">Safely navigate roadway network</td></tr>
<tr><td rowspan="8">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Approaches bicyclist from behind</td><td>AVS is traveling faster than bicyclist</td></tr>
<tr><td>AVS</td><td>2</td><td>Detects bicyclist and the speed of bicyclist</td><td></td></tr>
<tr><td>AVS</td><td>3</td><td>Decreases speed to match the speed of bicyclist</td><td>In a manner, such that the AVS matches bicyclist's speed once it reaches the following distance corresponding to bicyclist's speed</td></tr>
<tr><td>AVS</td><td>4</td><td>Determines that bicyclist can be legally passed, but only by encroaching into an oncoming lane of traffic</td><td>Assuming a two-lane bi-directional road</td></tr>
<tr><td>AVS</td><td>5</td><td>Detects that it can safely and lawfully pass the bicyclist without affecting traffic on the other side of the roadway</td><td></td></tr>
<tr><td>AVS</td><td>6</td><td>Passes the bicyclist using the approaching lane of traffic</td><td>Must pass the bicyclist at safe passing distance (minimum legal passing distance is 3 feet)</td></tr>
<tr><td>AVS</td><td>7</td><td>Continues along route</td><td></td></tr>
<tr><td>Post-conditions</td><td colspan="4">• The AVS, traveling at a faster speed than the bicyclist, is now ahead of the bicyclist on the roadway and has passed without any issues</td></tr>
</table>

Use Case	Roadway Object Detection and Reaction
Policies and Business Rules	California Vehicle Code Division 11 Chapter 3 Article 3 – Overtaking and Passing
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment
Inputs Summary	System Initialization Input: AVS must be able to identify a bicyclist and know the safe passing distance Human Input: None
Output Summary	AVS Data: Record of decisions made, record of accurate detection classification, path prediction of bicyclist, and video record of bicyclist actions and placement in roadway.

Source: SFCTA

Table 24: Use Case 4 Scenario 3: Normal Operating Conditions – Pedestrian Detection and Reaction

<table>
<tr><th>Use Case</th><th colspan="4">Roadway Object Detection and Reaction</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC4-S3: Normal Operating Conditions – Pedestrian Detection and Reaction</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the ability of an AVS to detect and stop for a pedestrian crossing the street</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS approaches a location where a pedestrian is crossing the street, and stops to allow the pedestrian to safely cross</td></tr>
<tr><td rowspan="3">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Detect pedestrian waiting to cross the street, detect pedestrian crossing the street, stop for pedestrian to cross</td></tr>
<tr><td>Pedestrian</td><td colspan="3">Safely navigate crosswalk</td></tr>
<tr><td rowspan="9">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Approaches a crosswalk</td><td>Or another street crossing area that is not marked, including unmarked crosswalks</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Pedestrian</td><td>2a</td><td>Waits at edge of road to cross at crosswalk</td><td></td></tr>
<tr><td>AVS</td><td>3a</td><td>Detects waiting pedestrian</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Pedestrian</td><td>2b</td><td>Steps into crosswalk</td><td></td></tr>
<tr><td>AVS</td><td>3b</td><td>Detects pedestrian in crosswalk</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

Use Case	Roadway Object Detection and Reaction			
	AVS	4	Comes to a stop at the crosswalk	At yield line or at a location that leaves sufficient space between AVS and crosswalk
	Pedestrian	5	Completes traversing the crosswalk	
	AVS	6	Resumes driving along its route	
Post-conditions	• Pedestrian has safely crossed the street and AVS can continue its route			
Policies and Business Rules	California Vehicle Code Division 11 Chapter 5			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment			
Inputs Summary	System Initialization Input: Location of crosswalks along route to be programmed into AVS (thought it can also identify them by pavement markings) Human Input: None			
Output Summary	AVS Data: Record of decisions made, record of accurate detection classification, path prediction of pedestrian, and video record of pedestrian's actions and placement in crosswalk			

Source: SFCTA

Table 25: Use Case 4 Scenario 4: Normal Operating Conditions – Object Detection

Use Case	Roadway Object Detection and Reaction			
Scenario ID & Title	*UC4-S4: Normal Operating Conditions – Object Detection*			
Scenario Objective	• Demonstrate the ability of an AVS to detect an object in the roadway and pass or drive over the object if conditions allow			
Operational Event(s)	• The AVS approaches an object, determines whether it can be driven over or needs to be passed, and proceeds when safe			
Actor(s)	Actor	Role		
	AVS	Detect object in the roadway, safely go around the object		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS	1	Approaches an object in its path	
	AVS	2	Detects the object	
	AVS	3a	Determines that the object can be driven over	Could be a leaf, plastic bag blown by the wind, etc.
	AVS	4a	Drives over the object	
	AVS	5a	Continues along route	
	AVS	3b	Determines that object cannot be driven over, but it can be passed without leaving the AVS's current lane of travel	Could be a stopped vehicle or construction equipment partially on the curb, or a small object such as a cone or animal
	AVS	4b	Maneuvers within its lane of travel around the object	
	AVS	5b	Continues along route	
	AVS	3c	Determines that the object cannot be driven over, and that it can be passed but only by encroaching into another lane of traffic	Could be a stopped vehicle, construction equipment, large animal, or a cone or flashing arrow signifying the lane is closed
	AVS	4c	Detects that it can safely and legally pass the object without affecting traffic in the other lane	

Use Case	Roadway Object Detection and Reaction			
	AVS	5c	Passes the object using the other lane of traffic	
	AVS	6c	Continues along route	
Post-conditions	• AVS has passed the object safely			
Policies and Business Rules	California Vehicle Code Division 11 Chapter 3 Article 3 – Overtaking and Passing			
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment			
Inputs Summary	System Initialization Input: Program how to identify objects and whether they need to be passed and whether they can be driven over, as well as the laws on passing and how to determine it is safe Human Input: None			
Output Summary	AVS Data: Record of decisions made, record of accurate detection, classification and object path, record of whether AVS decision was out of compliance with the law			

Source: SFCTA

Table 26: Use Case 4 Scenario 5: Degraded Conditions – Object Detection – Uncertainty in Course of Action

Use Case	Roadway Object Detection and Reaction			
Scenario ID & Title	*UC4-S5: Degraded Conditions – Object Detection – Uncertainty in Course of Action*			
Scenario Objective	• Manually navigate the AVS around an object when the AVS is not able to automatically navigate around the object			
Operational Event(s)	• The AVS approaches an object that it is not able to pass without encroaching into another lane of travel and is not able to determine how to safely pass the object • Operations staff are dispatched to the site to navigate the AVS around the object and allow the AVS to continue service			
Actor(s)	**Actor**	**Role**		
	AVS	Detect and properly respond to an object in the roadway		
	AVS Management System	Dispatch operations staff when necessary		
	Operations Staff	Manual operation of AVS		
Key Actions and Flow of Events	**Actor**	**Step**	**Key Action**	**Comments**
	AVS	1	Approaches an object in its path	
	AVS	2	Detects the object	
	AVS	3a	Is not able to determine how to pass the object	Could be due to weather or obstructed view of surrounding conditions
	AVS	3b	Is not able to determine when it is safe to legally pass the object. Comes to a safe stop.	
	AVS	4	Notifies AVS Management System and passengers that it has encountered an issue	
	AVS Management System	5	Sends out operations staff to manually navigate around the object	Alternatively, AVS operations staff on the shuttle will take control of the vehicle or remove debris from the roadway.
	Operations Staff	6a	Removes obstacle from AVS path	
	Operations Staff	6b	Navigates vehicle around object	
	AVS	7	Continues along route	

Use Case	Roadway Object Detection and Reaction
Post-conditions	• AVS passes the object, though with some delay
Policies and Business Rules	*None*
User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN020-v01 – Fall Back AVS-UN022-v01 – Disengagement Mechanism AVS-UN032-v01 – AVS Operation Monitoring AVS-UN035-v01 – Manual AVS Operation
Inputs Summary	System Initialization Input: How to identify when it is not able to decide and must alert the AVS Management System Human Input: Must come to the field
Output Summary	AVS Data: Record of decisions made, and times operations staff must step in to assist (Disengagement data with timestamp, location, and cause)

Source: SFCTA

Table 27: Use Case 4 Scenario 6: Failure Conditions – Object Misdetection

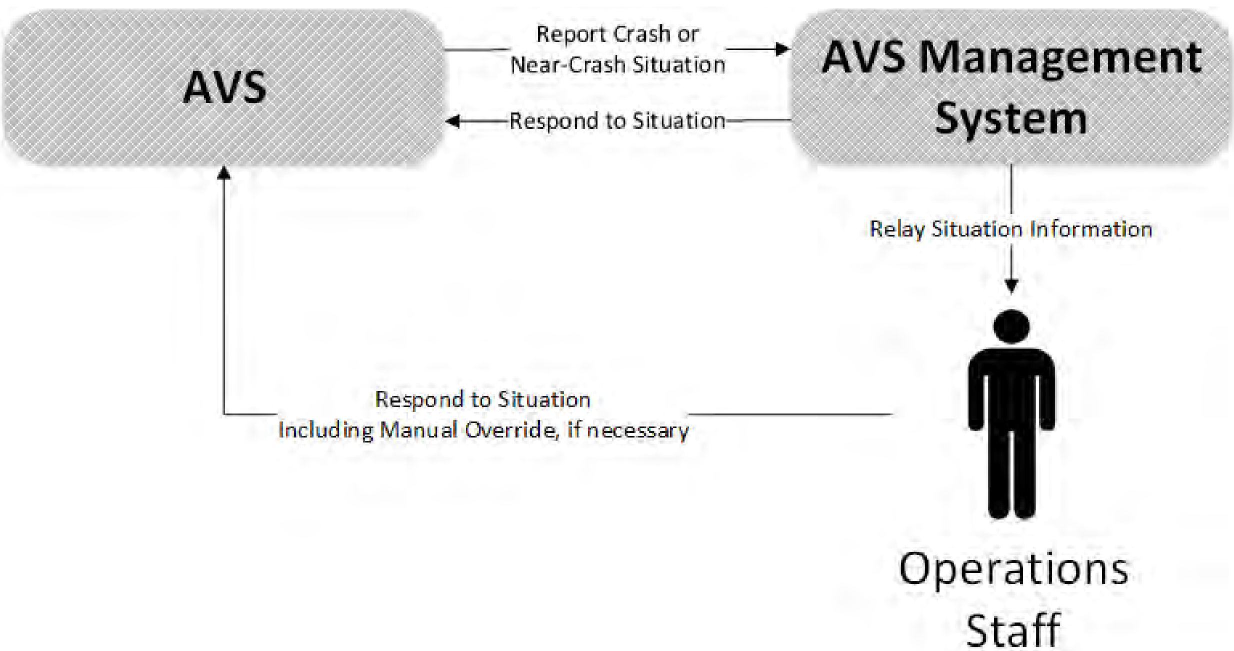
<table>
<tr><th>Use Case</th><th colspan="4">Roadway Object Detection and Reaction</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC4-S6: Failure Conditions – Object Misdetection</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate consequence of not detecting objects in the roadway environment, and to report an incident once it occurs</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS drives into an object that it does not detect</td></tr>
<tr><td rowspan="2">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Detect and properly respond to an object in the roadway</td></tr>
<tr><td rowspan="5">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Approaches an object in its path</td><td>Could be a vehicle or an object</td></tr>
<tr><td>AVS</td><td>2</td><td>Does not detect the object</td><td></td></tr>
<tr><td>AVS</td><td>3</td><td>Strikes the object</td><td></td></tr>
<tr><td>General</td><td>4</td><td>See UC5-S1 steps 3b-7b</td><td></td></tr>
<tr><td>Post-conditions</td><td colspan="4">• AVS has crashed into an object and must alert the AVS Management System to form a plan on how to proceed
• AVS will be removed from service until it can be determined what caused the failure to detect the object and the correction is made</td></tr>
<tr><td>Policies and Business Rules</td><td colspan="4">None</td></tr>
</table>

User Needs Traceability	AVS-UN015-v01 – Law Following – Open Traffic Environment AVS-UN020-v01 – Fall Back AVS-UN026-v01 – Tow or Road Clearance AVS-UN034-v01 – Incident Response
Inputs Summary	System Initialization Input: Same as Normal Operating Scenario, but in this case the input was not sufficient Human Input: Operations staff will be alerted and will assist the AVS in recovering from the incident
Output Summary	AVS Data: record of incident including video and all sensor data from the event data recorder; scheduled hours of operation; actual hours of operation

Source: SFCTA

6.5 Use Case 5: Crash Detection and Mitigation

This section describes scenarios where the AVS must detect it has been or is about to be involved in a crash and respond accordingly. In all scenarios, the expected outcome is that the AVS will react in a manner to avoid or minimize injury to humans.



Source: SFCTA

Figure 6: Use Case 5: Crash Detection and Mitigation Diagram

Table 28: Use Case 5 Scenario 1: Normal Operating Conditions – Avoiding an Incident

Use Case	Crash Detection and Mitigation	
Scenario ID & Title	*UC5-S1: Normal Operating Conditions - Avoiding an Incident*	
Scenario Objective	• Demonstrate ability of the AVS to detect an imminent crash situation, and to take the best action to avoid a crash or minimize the potential crash impact, if necessary • Provide a response to a crash situation	
Operational Event(s)	• AVS detects an imminent crash situation and responds to avoid the crash or mitigate its impact. The AVS then alerts the AVS Management System who initiates any additional response protocol.	
Actor(s)	Actor	Role
	AVS	Detect an imminent crash situation and take the best action to avoid a crash if necessary, report crashes to AVS Management System

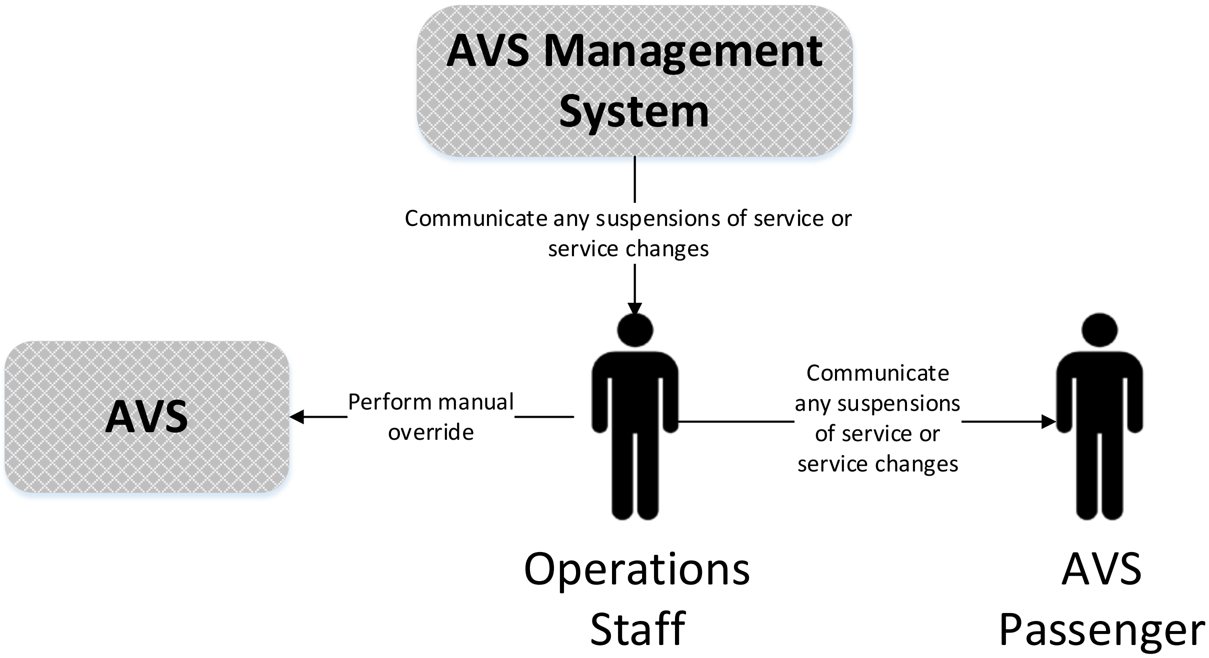
Use Case	Crash Detection and Mitigation			
	AVS Passenger	Exit the AVS and get examined for injuries if a crash occurs		
	Safety Driver	Notifies public safety officials, responds to scene, and restores service if a crash occurs		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS	1a	Detects that it has lost control on the roadway	
	AVS	1b	Detects that its path and the path of another vehicle will result in a side impact crash	
	AVS	1c	Detects that its path and the path of another vehicle will result in a head-on crash	
	AVS	1d	Detects that its path and the path of another vehicle will result in a rear-end crash	
	AVS	1e	Detects that its path will result in a road departure	
	AVS	1f	Detects that its path and the path of another object (pedestrian/bicycle/animal/object) will result in a crash	
	AVS	2	Immediately decreases speed and/or stops. Swerving may also be necessary to avoid obstacles in some circumstances.	To avoid or minimize the impact of a potential crash
	AVS	3a	Avoids the crash situation	
	AVS	4a	Reports the near-incident situation	
	AVS	5a	Continues its route	
	Safety Driver	6a	Assesses what led to the near-crash situation	AVS may be out of service during investigation
	AVS	3b	Is involved in a crash	
	AVS	4b	Immediately comes to a stop	
	AVS	5b	Notifies AVS Management System that a crash has occurred	
	Safety Driver	6b	Notifies 911 call center who will then dispatch first responders, tow truck, and other pertinent personnel to the crash scene	

Use Case	Crash Detection and Mitigation			
	AVS Passenger	7b	Exits the AVS and gets examined for injuries by first responders	
	Concierge	8b	Makes plans to restore service	AVS may be out of service during crash investigation and repairs
Post-conditions	• AVS is taken out of service, either because it is physically disabled and needs to be repaired or to update its software to avoid other crashes and near-misses in the future			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN019-v01 – Crash Avoidance AVS-UN020-v01 – Fall Back AVS-UN026-v01 – Tow or Road Clearance AVS-UN034-v01 – Incident Response			
Inputs Summary	System Initialization Input: Fall back and other response protocol to be programmed into AVS Human Input: Incident response protocol may require human input by operations staff to initiate			
Output Summary	AVS Data: Record of crashes and near-misses to be recorded including video and sensor data from the event data recorder; scheduled hours of operation; actual hours of operation			

Source: SFCTA

6.6 Use Case 6: AVS Operations Management

This section describes scenarios that involve AVS operations management.



Source: SFCTA

Figure 7: Use Case 6: AVS Operations Management Diagram

Table 29: Use Case 6 Scenario 1: Normal Operating Conditions – Preemptive Response to Adverse Weather

Use Case	AVS Operations Management	
Scenario ID & Title	*UC6-S1: Normal Operating Conditions - Preemptive Response to Adverse Weather*	
Scenario Objective	• Demonstrate the ability of the system manager to suspend AVS operations when weather that may affect operations is expected to occur (Note: AVS service will be suspended whenever Muni is suspended.)	
Operational Event(s)	• The AVS Management System suspends AVS operations • AVSs pull off the route to a safe location before impending weather arrives	
Actor(s)	Actor	Role
	AVS	Operate in an environment where it can operate as intended
	AVS Passenger	Not get stranded on an AVS that is not able navigate in adverse weather conditions

Use Case	AVS Operations Management			
	AVS Management System	Suspend operations when weather conditions approach that may impact the AVS's ability to navigate the roadway network, manually navigate AVS when necessary		
	Safety Driver	May take manual control of a vehicle if its sensors are disabled due to weather		
Key Actions and Flow of Events	Actor	Step	Key Action	Comments
	AVS Management System	1	Becomes aware of impending weather conditions	That are expected to impact the ability of the AVS to properly detect traffic control devices
	AVS Management System	2	Sends messages to operational AVSs and operations staff to suspend operations	
	AVS	3a	Completes route	If there is enough time to complete route and adverse weather conditions are expected to last more than a certain amount of time
	AVS Passenger	4a	Exits AVS at stop on route	See UC2-S1
	AVS	5a	Returns to Garage	See UC2-S1
	General	6a	Adverse weather conditions commence	
	AVS Management System	7a	Sends messages to AVSs to resume operations once it is safe to resume operations	
	AVSs	8a	Resumes operations	
	AVS	3b	Pulls off to a safe location off the roadway (e.g., a stop) and notifies passengers of adverse weather conditions	If there is not enough time to complete route or adverse weather conditions are expected to last less than a certain amount of time
	AVS Passenger	4b	May remain in the AVS or may exit the AVS	

Use Case	AVS Operations Management			
	General	5b	Adverse weather conditions commence	
	Safety Driver	6b	May take manual control of vehicle to complete route	If adverse weather conditions last longer than expected
	General	7b	Adverse weather conditions end	
	AVS Management System	8b	Sends messages to AVSs to resume operations	
	AVSs	19b	Resumes operations	
Post-conditions	• AVS resumes operations after suspending service during adverse weather			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN029-v01 – Managed AVS Operations AVS-UN032-v01 – AVS Operation Monitoring AVS-UN035-v01 – Manual AVS Operation			
Inputs Summary	System Initialization Input: None Human Input: Monitor weather conditions and alert AVS to suspend operations if necessary			
Output Summary	AVS Data: Record of time spent with suspended service and reason(s) recorded; scheduled hours of operation; actual hours of operation			

Source: SFCTA

Table 30: Use Case 6 Scenario 2: Normal Operating Conditions – AVS Route Modification

Use Case	AVS Operations Management	
Scenario ID & Title	*UC6-S2: Normal Operating Conditions – AVS Route Modification*	
Scenario Objective	• Demonstrate the ability of the system manager to modify AVS routes when planned conditions along the current AVS route that will not allow the AVS to operate as intended are expected to occur	
Operational Event(s)	• The AVS Management System modifies the AVS route • The AVS begins operation along the new route	
Actor(s)	Actor	Role
	AVS	Travel on roadways that the AVS is capable of navigating

Use Case	AVS Operations Management			
	AVS Management System	Send new route information to AVSs		
	Concierge	Make travelers aware of any service changes		
	Safety Driver	Specify the route on which the AVS should travel, manually drives the AVS when it is not able to do so on its own		
Key Actions and Flow of Events	**Actor**	**Step**	**Key Action**	**Comments**
	AVS	1	Approaches a road closure along its route	Road closure is unplanned
	AVS	2	Is not able to determine how to pass around the road closure	
	AVS	3	Notifies AVS Management System that it does not know how to proceed	
	Safety Driver	4	Becomes aware of a road closure or road condition	That will not allow the AVS to effectively run its current route
	Safety Driver	5	Manually navigates vehicle	Through a detour to get around unplanned closure
	AVS	6	Continues along route	
	AVS Management System	7	Develops a new route that navigates around the closure or condition	
	AVS Management System	8	Sends new routes to AVSs	
	AVS Management System	9	Updates roadside and online shuttle route information	Detour notices at AVS stops
	AVS	10	Begins traversing new route	When specified by AVS Management System
Post-conditions	• AVS can continue its route, and may know to travel on a new route the next time it reaches this location			
Policies and Business Rules	*None*			
User Needs Traceability	AVS-UN017-v01 – Law Following – Temporary Traffic Control AVS-UN018-v01 – Route Deviation AVS-UN022-v01 – Disengagement Mechanism AVS-UN027-v01 – Route Definition AVS-UN029-v01 – Managed AVS Operations			

Use Case	AVS Operations Management
Inputs Summary	System Initialization Input: Program road closures or conditions so this type of scenario is minimized, program new route Human Input: Manual navigation
Output Summary	AVS Data: Record of decisions made, and record of times manual intervention is required (Disengagement data with timestamp, location, and cause)

Source: SFCTA

Table 31: Use Case 6 Scenario 3: Failure Conditions – Manual or System Override

<table>
<tr><th>Use Case</th><th colspan="4">AVS Operations Management</th></tr>
<tr><td>Scenario ID & Title</td><td colspan="4">UC6-S3: Failure Conditions – Manual or System Override</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">Demonstrate the ability of the system manager to override an AVS's internal system and bring the AVS to a safe stop</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The AVS begins acting in an erratic or unexpected way
• The AVS Management System senses this and overrides the system to bring the AVS to a stop. Alternatively, it notifies operations staff to override the system to bring it to a stop.</td></tr>
<tr><td rowspan="3">Actor(s)</td><td>Actor</td><td colspan="3">Role</td></tr>
<tr><td>AVS</td><td colspan="3">Travel safely on roadways</td></tr>
<tr><td>Safety Driver</td><td colspan="3">Stop the AVS from behaving unsafely</td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Actor</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>AVS</td><td>1</td><td>Traverses its regular route</td><td></td></tr>
<tr><td>AVS</td><td>2</td><td>Begins behaving in an unsafe manner</td><td>Perhaps it has been hacked, has a malfunctioning sensor, or has lost connectivity</td></tr>
<tr><td>Safety Driver</td><td>3</td><td>Sees the AVS is behaving in an unsafe manner</td><td></td></tr>
<tr><td>Safety Driver</td><td>4</td><td>Decides the safest course of action is to stop the AVS immediately</td><td></td></tr>
<tr><td>Safety Driver</td><td>5</td><td>Overrides the AVS, bringing it to a stop</td><td></td></tr>
<tr><td>AVS</td><td>6</td><td>Comes to a complete stop, opens door, and notifies passengers to alight</td><td>So, passengers can alight</td></tr>
<tr><td>Post-conditions</td><td colspan="4">AVS has come to a complete stop, AVS passengers can safely alight, and the reason for the issue can be analyzed</td></tr>
</table>

Use Case	AVS Operations Management
Policies and Business Rules	*None*
User Needs Traceability	AVS-UN022-v01 – Disengagement Mechanism AVS-UN037-v01 – AVS Override / Shut Off
Inputs Summary	System Initialization Input: None Human Input: Manual navigation
Output Summary	AVS Data: Record that manual intervention of a full system override was required (Disengagement data with timestamp, location, and cause); scheduled hours of operation; actual hours of operation

Source: SFCTA

6.7 User Needs to Scenarios Summary

Table 32 provides the traceability between the user needs and the scenarios presented previously in this section.

Table 32: User Needs to Scenarios Summary

User Need Identification	User Need Title	Applicable Scenarios
AVS-UN001-v01	Boarding AVS	UC1-S1
AVS-UN002-v01	Alighting AVS	UC1-S1
AVS-UN003-v01	Traveler Information	UC1-S1
AVS-UN004-v01	Passenger Safety Alert	UC1-S2
AVS-UN005-v01	Concierge	UC1-S1 UC2-S2 UC2-S3 UC6-S2
AVS-UN006-v01	ADA Accessibility	UC1-S3
AVS-UN007-v01	Stop for Passenger Boarding	UC1-S1
AVS-UN008-v01	Stop for Passenger Alighting	UC1-S1
AVS-UN009-v01	Ridership Data	UC1-S1
AVS-UN010-v01	ADA Accessibility	UC1-S3
AVS-UN011-v01	Quiet Car Alert	UC1-S1
AVS-UN012-v01	Manual Fueling	UC2-S1 UC2-S2 UC2-S3
AVS-UN013-v01	Transportation Management System	UC1-S1
AVS-UN014-v01	Security Camera	UC1-S2
AVS-UN015-v01	Law Following – Open Traffic Environment	UC1-S1 UC2-S4 UC3-S1 UC3-S2 UC3-S4 UC4-S1 UC4-S2 UC4-S3 UC4-S4 UC4-S5 UC4-S6
AVS-UN016-v01	Law Following – Regulatory	UC3-S1 UC3-S3
AVS-UN017-v01	Law Following – Temporary Traffic Control	UC3-S3 UC6-S2
AVS-UN018-v01	Route Deviation	UC6-S2
AVS-UN019-v01	Crash Avoidance	UC3-S2 UC5-S1
AVS-UN020-v01	Fall Back	UC3-S4 UC4-S5 UC4-S6

User Need Identification	User Need Title	Applicable Scenarios
		UC5-S1
AVS-UN021-v01	Detection Arbitration	N/A
AVS-UN022-v01	Disengagement Mechanism	UC1-S2 UC4-S5 UC6-S2 UC6-S3
AVS-UN023-v01	Uncertainty in Course of Action	UC3-S4
AVS-UN024-v01	Operational Design Domain	All scenarios
AVS-UN025-v01	Climate Control	UC1-S1
AVS-UN026-v01	Tow or Road Clearance	UC4-S6 UC5-S1
AVS-UN027-v01	Route Definition	UC6-S2
AVS-UN028-v01	End of Service Period	UC2-S1 UC2-S2
AVS-UN029-v01	Managed AVS Operations	UC6-S1 UC6-S2
AVS-UN030-v01	Data Transfer	All scenarios
AVS-UN031-v01	AVS Charge	UC2-S1 UC2-S2 UC2-S3
AVS-UN032-v01	AVS Operation Monitoring	UC4-S5 UC6-S1
AVS-UN033-v01	Managed AVS Charging	UC2-S1 UC2-S2 UC2-S3 UC2-S4 UC2-S5
AVS-UN034-v01	Incident Response	UC4-S6 UC5-S1
AVS-UN035-v01	Manual AVS Operation	UC4-S5 UC6-S1
AVS-UN036-v01	Assistance for People with Disabilities	UC1-S3
AVS-UN037-v01	AVS Override / Shut Off	UC6-S3
AVS-UN038-v01	Manual Data Collection	UC1-S1

Source: SFCTA

7 Summary of Impacts

7.1 General

This section provides a summary of the operational and organizational impacts of the proposed system on stakeholders and other supporting entities. This includes a section on temporary impacts that are expected to occur while the new system is being developed, installed, and tested.

7.2 Operational Impacts

The AVS system will be a small fleet of AVSs on public roads in mixed traffic. The following are potential operational impacts:

1. Increased travel time on the Corridor: Overall traffic operations on the roads served may be impacted. This could lead to an increase in travel time due to the presence of these slow moving AVSs on the roadway, particularly on YBI where other vehicles travel faster. The hesitance of other drivers to interact with autonomous vehicles may also increase travel time.
2. Reduced Congestion: If ridership on the AVSs increases, there could be a decrease in local congestion. This would be due to TI/YBI visitors choosing to just "park once" and not move their personal vehicles within the area, as well as due to potential higher transit usage.
3. Increased use of multimodal options: With the cars left at parking lots, users will avail of other multi-modal options including walking, biking, transit, ferry, car share program or others.
4. Shift in Boarding/Alighting: Boarding and alighting behavior on SFMTA bus routes servicing TI/YBI may be shifted in response to the location of transfer points to the AVS system and whether they provide a closer service to final destinations servicing TI/YBI. In a long-term deployment, SFMTA may reroute the Route 25 Treasure Island line if the AVS is successful at providing intra-island service on the island.

7.3 Organizational Impacts

The implementation of AVS service on the islands is expected to result in minor organization impacts for the stakeholder agencies (SFCTA, SFMTA, TIDA) that may have to take on additional responsibilities associated with the AVS system as identified in the Stakeholder's Roles and Responsibilities section.

The AVS Management System/vendor will be responsible for operations and maintenance of the system. This will include ensuring the AVSs are operating as planned, safely and on schedule. To do this the AVS Management System will need to facilitate a system for monitoring the AVSs, including staffing a back office in the TI/YBI area and deploying operations staff as a "concierge" for passenger questions and on-board monitoring. Maintenance will be done by the vendor with experience maintaining AVSs, such as the vehicle manufacturer, minimizing organizational impacts to existing agencies.

In the long term, this free service could increase shuttle and transit demand to the TI/YBI area, potentially guiding the planning of whether Muni and other transit service routes may need to provide greater capacity through increased frequency or larger capacity shuttle/bus.

7.4 Impacts During Pilot

Regulatory approval at the state, and federal level will be required. This is important to consider because of the amount of time it could take to complete.

The AVSs will be procured from an external vendor. Federal funds are being used for this project, so purchasing the vehicle would be subject to federal procurement regulations such as Buy America. Leasing the vehicles through a subcontractor agreement may not be subject to the same requirements.

The route will be mapped virtually by the vendor. Depending on the final route, no major infrastructure investments by local governments or agencies are anticipated to be necessary, other than potential additional signage, ADA, and storage and maintenance facility upgrades.

On-site testing and route mapping will need to occur before the pilot begins passenger operations. This will need to be done on closed roads first, before testing on TI/YBI roads and could be done at night or during off-peak times. Additionally, the AVSs will be tested on the roads without passengers before allowing passenger service. Introducing AVs into mixed traffic operations will be challenging, both for human drivers and for the autonomous vehicles, as both will have to deal with the unfamiliar behavior of the other entity. If any potential concerns arise during preliminary testing and operations that inform the actual capabilities of the AVSs, the route alignments and other service characteristics may be modified.

8 Analysis of the Proposed System

8.1 General

This section provides a summary and analysis of the benefits, limitations, advantages, and disadvantages of the proposed system, as well as any alternatives and tradeoffs considered.

8.2 Potential Benefits

The AVS system will potentially enhance many functionalities of the transportation network and provide additional capabilities, for example the addition of:

- Service that reduces the distance from transit to area destinations (FMLM)
- Autonomous vehicle technology to shuttle service
- Electric vehicle operations to shuttle service

By providing a safe, clean, reliable FMLM transportation option to TI/YBI, all residents and visitors will have a variety of mobility options, reducing demand for personal vehicles. The zero emissions or reduced emissions AVS combined with the reduced demand for personal vehicles will reduce greenhouse gas emissions for TI/YBI residents and visitors.

In addition, the lessons learned from this project will potentially enable more AVSs to be successfully deployed. The potential safety, mobility and environmental benefits realized from additional deployments will improve FMLM connections in more areas, further reducing the demand for personal vehicles.

8.3 Risks and Limitations

Autonomous vehicles are an emerging technology solution that has not yet been fully tested under all conditions. Many test projects have been implemented in cities around the world, but there have been limited operations in mixed traffic, especially a high-pedestrian environment like TI/YBI. There could be real safety risks associated with vehicles that are not FMVSS compliant and will be operating on public roads with other road users that will be constantly changing due to construction. Because of these safety risks, TIMMA will ensure proper insurance policies are in place and the shuttle vendor is operating the AVS as proposed to manage this risk.

8.4 Future Deployment Features

Some features that are desirable or not applicable to the pilot may be more desirable for a long-term deployment in the future. In the context of this project, the future is defined as being after the next phases of the Treasure Island development are completed and residents are living on the island. Features that will be more desirable in the full deployment include on-demand boarding/alighting and coordinating with signals. Current desirable features that will be essential in the full deployment will be 24/7 operations and hybrid/electric vehicles.

Appendix A: Goals, Objectives and Evaluation Framework

AV Shuttle Pilot
Goals, Objectives and Evaluation Framework

TIMMA AV Pilot Goals		TIMMA AV Pilot Objectives	Hypothesis	AV Pilot Performance Metric(s)	Performance Metric Justification	Performance Metric Data Source	Scenario Traceability
Safety	1. Without risking safety of the public, understand the public safety implications of an AV Shuttle.	1A. Protect the safety of passengers & road users in TI/YBI during pilot operations	AV shuttle technology is safely deployed on TI/YBI during pilot operations.	1A1. Number of collisions and incidents (including injuries).	Documenting all safety incidents occurring during the pilot	Shuttle Operator Collision Report (to include video, time, date, location, collision with what, injuries, which parts of the vehicle were impacted by the collision, damage)	UC4-S6; UC5-S1
				1A2. Rate of incidents/collisions per mile of operation.	A rate normalizes the data and puts the number of incidents and collisions into context. This data can be compared to or aggregated with other projects or pilots and help determine a future service benchmark.	Shuttle Operator Collision Report (to include video, time, date, location, collision with what, injuries, which parts of the vehicle were impacted by the collision, damage)	UC4-S6; UC5-S1
		1B. Explore whether AV shuttle technology can safely address the driving challenges of TI/YB.	The pilot provides data to inform long term decisions about safe AV Shuttle deployments.	1B1. Number, location and cause of AV system disengagements (including operating system malfunction or shut down due to an unknown operating parameter) and other potential safety incidents (including number, location and context of situations when the shuttle encountered safety events and didn't disengage).	Identifying the number of disengagements will identify if the service can potentially operate without a concierge in the future. Knowing the location of disengagements can identify operating restrictions or causes of interference so modifications can be made for improved performance. Gathering data of instances when the AV shuttle can safely maneuver risky situations will help provide a broader picture of AV technology capabilities.	Shuttle Operator	UC1-S2; UC3-S2; UC3-S3; UC3-S4; UC4-S5; UC4-S6; UC5-S1; UC6-S1; UC6-S2; UC6-S3
			An AV Shuttle is perceived by passengers and road users as a safe long term solution for TI	1B2. Perceived personal safety and overall system safety when riding or encountering shuttle	Perceived safety of the system may be different than actual operational safety metrics. Initial perceived safety metrics (both personal and of system overall) and perceived safety metrics from re-occurring users will be important to understand any stakeholder opinion trends.	Shuttle Operator (User Survey)	UC1-S1
Mobility	2. Understand if AV Shuttle technology can meet TIMAA's intra-island transportation service needs at TI/YBI.	2A. Explore whether AV shuttle service can be accessible to everyone	AV shuttles can carry bicycles and personal transportation devices, strollers & luggage or operator has a roadmap to provide accommodations under full deployment.	2A1. Number of bicycles on board the AV shuttles. Number of times bicyclists could not board due to capacity. User survey of ease of use for bicycles, personal transportation devices, strollers & luggage.	Having shuttles that are capable of easily, safely and securely boarding, alighting, and storing bicycles, personal transportation devices, strollers & luggage during the transit trip provides for an integrated multi-modal transportation system.	Shuttle Operator, including user survey	UC1-S1; UC1-S3
			AV shuttles are capable of serving individuals with disabilities without human assistance	2A2. Number of times people with disabilities (by category of disability) were able to hail, board, secure themselves or alight without requiring concierge assistance. Number of times concierge assistance was required to hail, board, secure or alight (to derive a rate of success). User perceptions of all trip elements (including hailing or reservation system) from persons with disabilities through user survey.	This measure will help determine if the service can operate without a concierge. User survey provides context of challenges users with disabilities face when using AV system	Shuttle Operator	UC1-S1
			AV shuttles are not a barrier to disadvantaged or vulnerable users.	2A3. Vulnerable or disadvantage user perceptions, measured through before and after user survey.	This performance measure can identify if there are any significant differences in perception that might become barriers for disadvantaged or vulnerable users.	Shuttle Operator (User Survey to include gender identification, race, income demographics, vehicle ownership. Focus group of island residents)	UC1-S1
		2B. Explore the AV Shuttle's ability to meet the intra-island needs of users in TI/YB	AV shuttle service can meet TI/YB user needs	2B1. AV Shuttle service use and perceptions as measured through user survey	Measure user's perception, such as how often do they use the shuttle and for what purposes, how does this service fit in their overall trip, how would the trip be made if the shuttle was not available, how did they hear about the service. Review SFMTA stationless permit program user survey as a starting point.	Shuttle Operator (User Survey)	UC1-S1
Operations	3. Understand TIMMA's organizational capabilities and infrastructure needs to operate an AV shuttle.	3A. Explore whether AV shuttle technology can meet TIMMA's TI/YB shuttle operation needs	AV shuttle operations are secure from cyber attacks.	3A1. Percent of time during operating hours the system is shut down due to operating system security breaches. Number of security breach attempts & number of successful breaches.	The AV operating system should avoid service disruption due to security breaches in order to meet performance goals and provide safe operations. Measures the vulnerability of the AV system to cyberattacks	Shuttle Operator	Not applicable to scenarios
			AV shuttle operations can provide accurate, reliable and timely data	3A2. Data is received accurately, per standards and on time.	This metric evaluates whether the data standard and reporting requirements are met	Shuttle Operator	Not applicable to scenarios
			AV shuttle operation costs are equal or less to other similar public services	3A3. Annualized operating expense per service mile	Annualizing the operating expense over the three month pilot project will help determine if the costs per revenue mile are comparable to other existing transit services in the San Francisco bay area in order to understand how the service may complement existing transit services.	Shuttle Operator	
		3B. Explore whether AV shuttle technology can meet TIMMA's TI/YB shuttle service needs and constraints	AV shuttles can meet TIMMA's shuttle service requirements	3B1. Adherence to operating and performance requirements that are accurate with timely reporting of data (operating hours, ridership, disengagements, safety, emissions)	AV shuttle performance should meet contracted service operations and reporting goals so that any service or operation adjustments can be made in a timely manner.	HNTB	Not applicable to scenarios
			AV shuttles can provide reliable (without disruptions) service	3B2. Actual hours in service as compared to anticipated scheduled hours of service. Dwell times by stop and route durations histograms. If on-demand, % of requests fulfilled, response time histogram. Percent of time during operating hours the system is out of service and cause of service disruption.	Metrics are intended to measure system consistency and reliability for users. AV shuttle operations should be reliable. Understanding service disruptions and causes for service disruption will help determine if the technology is reliable for TIMMA operations.	Shuttle Operator/HNTB (Histogram should include statistical information of data including average, mean and standard deviation)	UC1-S1; UC1-S2; UC2-S1; UC2-S2; UC2-S3; UC2-S4; UC2-S5; UC4-S6; UC5-S1; UC6-S1; UC6-S3
			AV shuttle operator will meet or have a roadmap to meet CA public fleet emission goals (all electric by 2040)	3B3. Number of electric, hybrid or alternative fuel vehicles in pilot. Grams CO2 per passenger mile (if not ZEV) consistent with CARB regulations. Year operator would be able to meet CA public fleet emissions goals.	Measures how many electric or alternative fuel vehicles can be placed in operation during pilot, and the year in which 100% electric vehicles can be expected to be commercially available.	Shuttle Operator	Not applicable to scenarios
Share lessons learned	4. Gather insights from the public during pilot and share lessons learned with community and key stakeholders.	4A. Provide opportunity to demonstrate AV technology to key stakeholders and community groups through pilot.	The AV pilot is a learning opportunity for key stakeholders and community groups	4A1. Number of total people participating in a demonstration to key stakeholders and community members	The AV pilot at Treasure Island will be an opportunity to observe and learn about AV Shuttle technology and operations.	Shuttle Operator	Not applicable to scenarios
		4B. Upon pilot completion, pilot results are shared with stakeholders	AV Pilot outcomes are collected and shared with stakeholders.	4B1. Key participant end of pilot survey	Stakeholder input on the knowledge gained from the pilot project will help inform future potential project opportunities.	HNTB (Stakeholder Survey)	Not applicable to scenarios

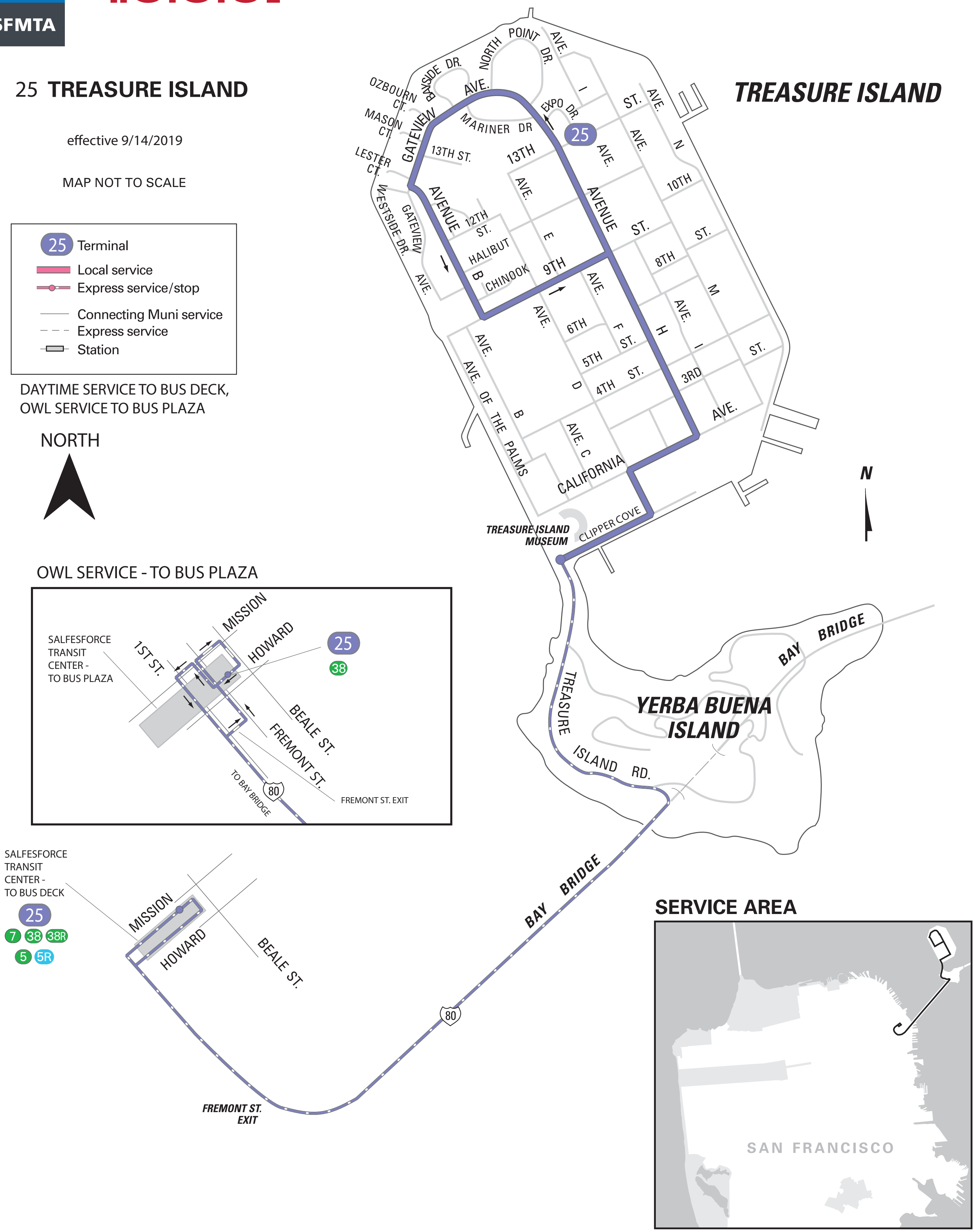
Appendix B: Muni Treasure Island Service Map

SFMTA

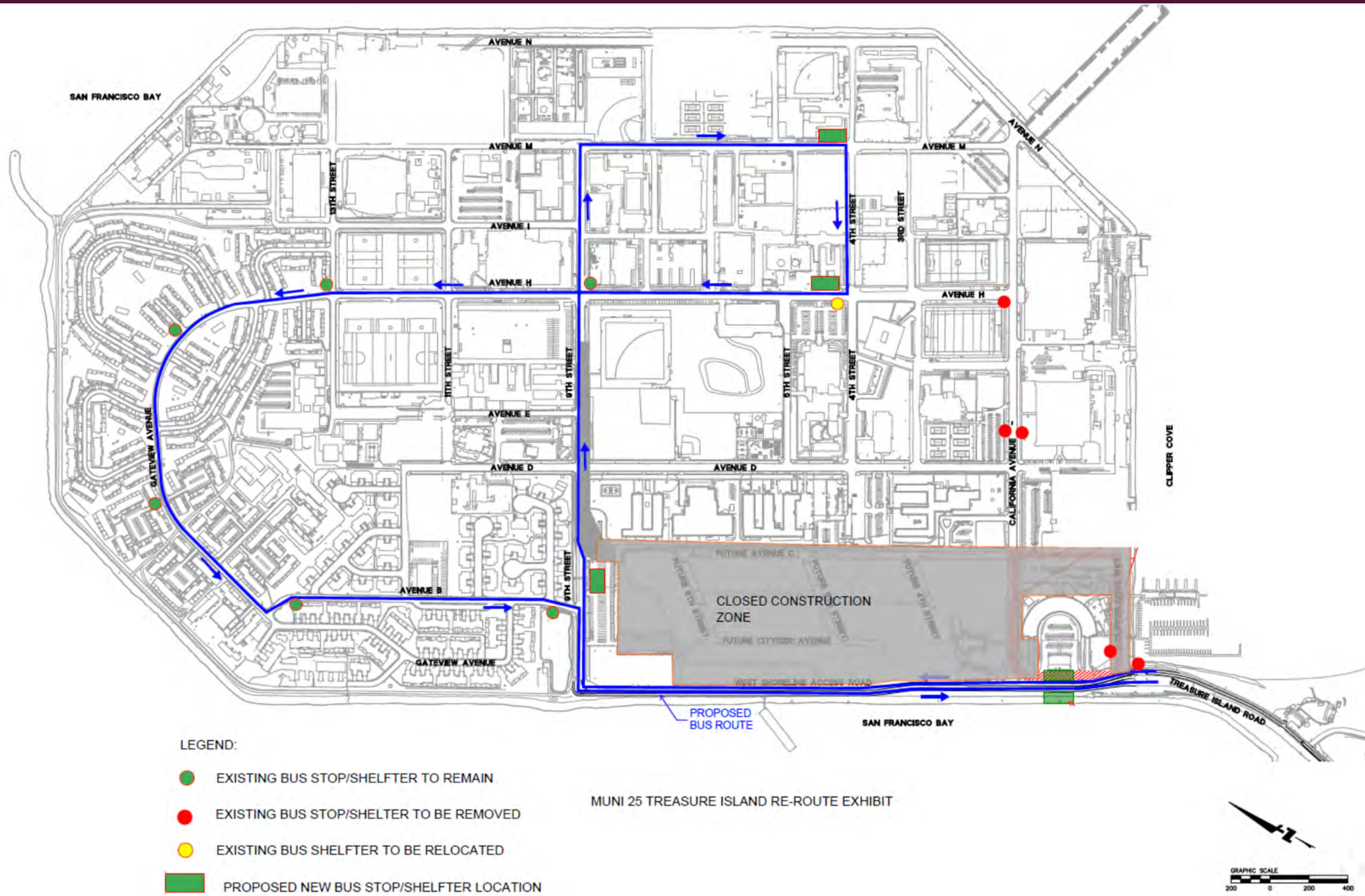
25 TREASURE ISLAND

effective 9/14/2019

MAP NOT TO SCALE



TREASURE ISLAND MUNI 25 RE-ROUTE



Appendix C: TITIP Figures

TICD
Treasure Island Community Development, LLC

*Now the Salesforce Transit Center

TREASURE ISLAND TRANSPORTATION IMPLEMENTATION PLAN

Figure 5.1

PROPOSED TRANSIT SERVICE

Proposed Bus & Shuttle Routes-TI.ai

TICD
Treasure Island Community Development, LLC

TREASURE ISLAND TRANSPORTATION IMPLEMENTATION PLAN

Figure 5.2

PROPOSED BUS AND SHUTTLE ROUTES - TREASURE ISLAND

Appendix D: Route Planning Memorandum

TIMMA AV ROUTE PLANNING MEMORANDUM

TIMMA AV Shuttle

DRAFT MEMORANDUM

March 2020

PREPARED FOR

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1455 Market Street
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PREPARED BY

HNTB Corporation
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HNTB

Treasure Island AV Shuttle Pilot
Potential Routes

Introduction

The Treasure Island Mobility Management Agency (TIMMA) is charged with implementing an integrated multi-modal plan, including intra-island shuttles, in phases that align with the development efforts of Treasure Island Community Development, LLC (TICD) and the oversight of the Treasure Island Development Authority (TIDA). Automated vehicle (AV) shuttles will be piloted on the island as part of a holistic solution to deliver safe and sustainable mobility options with equitable access for the entire Island community.

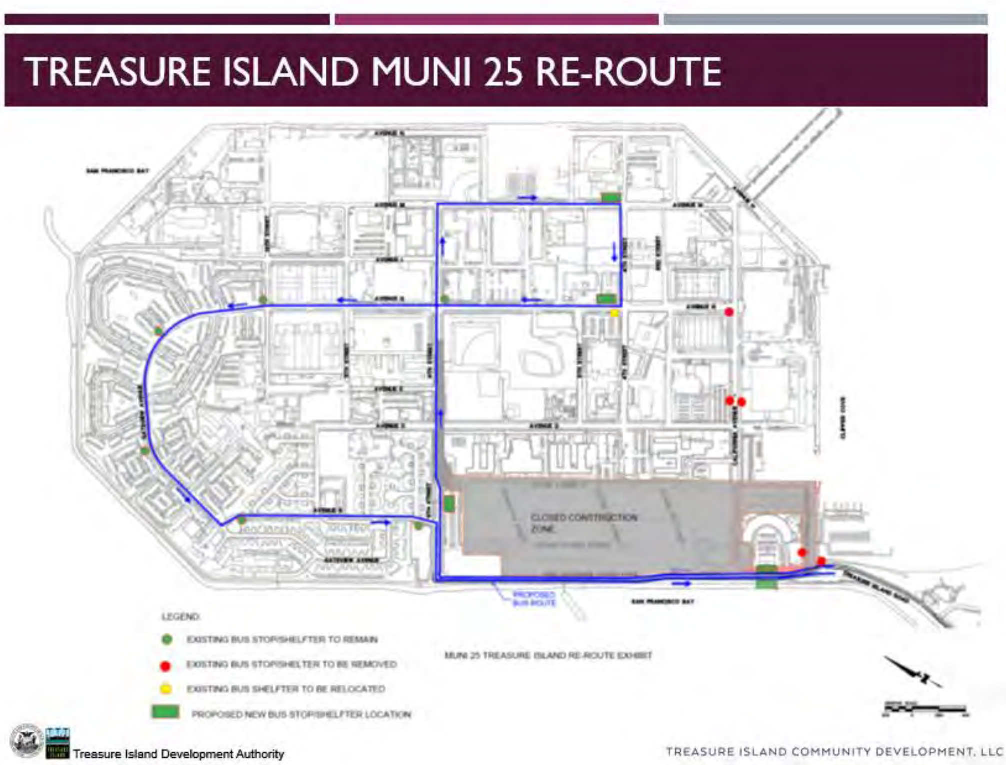
Purpose

The purpose of this route planning memorandum is to identify the considered routes for the shuttle pilot and the locations for the potential storage and maintenance facility. While routes are identified in the Treasure Island Transportation Implementation Plan (TITIP), the routes in the TITIP only apply to the final conditions. This document presents routes that are viable within the phase of construction during the time of pilot. These route options will be discussed with the potential AV shuttle vendor(s) during the procurement process to identify their preferred route for the shuttle services based on their vehicle capabilities.

Methodology

To develop the routes, a meeting was conducted with SFCTA, SFMTA, TIDA, and HNTB. The project team reviewed the construction phasing, the updated San Francisco Municipal Railway (Muni) bus route, and existing landmarks to come up with options for the shuttle service that serve the needs of the island. During this meeting the following elements were noted:

- Due to construction closures (including Clipper Cove Way), Muni Route 25 will be rerouted as shown in the following image.



Both the north and south ends of Avenue M will be closed during the shuttle pilot period (spring & summer of 2021), with access open only to businesses on the center area of the road.
At least one entrance to the admin building will remain open throughout the entire construction period

- Admin Building parking lot circulation is counterclockwise
- In Yerba Buena Island:
    - In June 2021, South Gate will still be under construction with bicycle ramp access only on the weekends
    - The only destination on YBI will be the coast guard (not a lot of demand)
    - AV shuttles may need to service YBI only during specific hours (about an hour per day)
    - Consider YBI route as an on-demand route or a test route (with no passengers)
- It is currently assumed that the AV shuttle pilot can share stops with Muni Route 25 (SFMTA to confirm).

Route Options

Three route options were developed. In addition, potential locations for storage and maintenance facilities were identified. The following section describes each of the options, along with the advantages and disadvantages.

Route 1 – Treasure Island Only

Figure 1 shows the AV shuttles' route along with the major landmarks within the island, potential bus stops, and the direction of the shuttle for Treasure Island only route 1 option. Route 1 starts at the Admin Building and makes a counterclockwise loop around the admin building parking lot. The shuttle then heads north on Avenue of the Palms and makes a right on 9th Street. The shuttle then heads east and makes a left onto Avenue H. The shuttle continues straight along Avenue H and Gateway Avenue then makes a left onto Avenue B. The shuttle continues south on Avenue B then makes a right onto 9th Street. The shuttle continues on Avenue of the Palms until it reaches the Admin Building and starts the route over. The AV shuttles' bus stops will be shared with Route 25 bus stops.

The advantage of Route 1 is that the route is shorter, so fewer shuttles may be needed to maintain a headway than Route 2. The disadvantage of Route 1 is that it includes a left turn which could impact performance and may require infrastructure adjustments to improve sight distance.

Route 2 – Treasure Island Only

Figure 2 shows the AV shuttles' route along with the major landmarks within the island, potential bus stops, and the direction of the shuttle for Treasure Island only route 2 option. Route 2 starts at the Admin Building and makes a counterclockwise loop around the admin building parking lot. The shuttle then heads north on Avenue of the Palms and makes a right on 9th Street. The shuttle then heads east and makes a right onto Avenue M. The shuttle makes a right on 4th Street and another right onto Avenue H. The shuttle continues straight along Avenue H and Gateway Avenue then makes a left onto Avenue B. The shuttle continues south on Avenue B then makes a right onto 9th Street. The shuttle continues on Avenue of the Palms until it reaches the Admin Building and starts the route over. The AV shuttles' bus stops will be shared with Route 25 bus stops.

The advantages of Route 2 are that left turn at Avenue H and 9th Street is eliminated, which should improve shuttle performance, and the route covers more destinations minimizing the walking distance. The disadvantage is that the route is longer, which may increase the number of required shuttles to maintain the same headway as Option 1.

Route 3 – Treasure Island and Yerba Bueno Island

Figure 3 shows the AV shuttles' route along with the major landmarks within the island, potential bus stops, and the direction of the shuttle for both Treasure Island and Yerba Buena Island route 3 option. Route 3 starts with either Route

1 or Route 2. Once the shuttle reaches the Admin Building at the end of the route, instead of stopping at the Admin Building, the shuttle continues on to Yerba Buena Island (YBI). The shuttle makes a left on Macalla Road and continues to the end of the road. At the end of the road, the shuttle makes a hairpin turn down North Gate Road and continues along North Gate. The shuttle makes a left on Army Road and then a U-turn at the end near the Pier. The shuttle then makes a right on North Gate Road, then another right onto Macalla Road. At the end of the Macalla Road, the shuttle makes a right on Treasure Island Road and turns back into the Admin Building parking lot to start the route over. YBI will have four stops as shown in Figure 3.

The advantage of Route 3 is that is provides shuttle coverage to YBI and tests the impact of steep grades on the shuttle performance. The disadvantage is that there won't be many visitors, residents, or workers on that side of the island, so the route will be mostly unused. The route would require more shuttles which would increase the cost of the project. In addition, this route requires coordination with US Coast Guard, as this is the only access route to their facilities in YBI.

Potential Storage and Maintenance Facilities

Four (4) options were proposed for storage and maintenance facility locations as shown in Figure 4. . The options were:

- ***Admin Building***
  The basement of the Admin Building provides locked storage space, but shuttles may not be able to navigate under the building by themselves, which would require assistance from the onboard concierge. The storage area would likely need an electric service and equipment upgrade. Additional information about utility service in this area is needed.

- ***Existing shuttle parking near Mersea***
  The existing shuttle parking near Mersea provides a space near existing electric vehicle chargers but would require fencing in the middle of the parking lot and would be prone to vandalism. New electric lines would need to be run for the shuttle chargers. This lot serves the main tourist destination in the island and is frequently in use, any operations would need to occur during off hours (during the weekdays and earlier in the day).

- ***Back of Mersea parking lot near existing fence area***
  The area in the back of the Mersea parking lot is located near an existing fenced in area. This area would be easy to fence in without looking out of place but would still be easy to vandalize the vehicles because it's outside. New electric line would need to be run for the shuttle chargers.

- ***Building 260***

  Building 260 may have space to store the shuttles and has better security than the parking lot. The storage area would likely need to have the electric upgrade. Additional information about utility services and available space in this building is needed.

Treasure Island AV Shuttle Pilot
Potential Routes

Figure 1: Route Option 1 with Bus Stops – Treasure Island Only

Treasure Island AV Shuttle Pilot

Potential Routes

Figure 2: Route Option 2 with Bus Stops – Treasure Island Only

Treasure Island AV Shuttle Pilot
Potential Routes

Figure 3: Route Option 3 with Bus Stops – Treasure Island Only and Yerba Buena Island

Figure 4: Potential Storage and Maintenance Facility Locations

TIMMA AV System Requirements

SYSTEM REQUIREMENTS

March 2021

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List of Acronyms and Abbreviations

ADA	Americans with Disabilities Act
ADS	Automated Driving Systems
AVS	Autonomous Vehicle Shuttle
CA MUTCD	California Manual on Uniform Traffic Control Devices
Caltrans	California Department of Transportation
ConOps	Concept of Operations
DSRC	Dedicated Short-Range Communications
FHWA	Federal Highway Administration
FMLM	First-Mile/Last-Mile
FMVSS	Federal Motor Vehicle Safety Standards
FR	Functional Requirements
GTFS	General Transit Feed Specifications
NF	Non-Functional Requirements
NHTSA	National Highway Traffic Safety Authority
OR	Operational Requirements
PR	Performance Requirements
TIDA	Treasure Island Development Authority
TIMMA	Treasure Island Mobility Management Agency
TITIP	Treasure Island Transportation Implementation Plan
TI/YBI	Treasure Island and Yerba Buena Island
USDOT	United States Department of Transportation
USG	United States Government

1 Introduction

This Systems Requirements document is intended to provide the requirements that drive the specifications, design, development, implementation, integration and testing of the Treasure Island Mobility Management Agency (TIMMA) Autonomous Vehicle Shuttle (AVS) Pilot Project. The System Requirements document is a "black box" description of what the facility must do, but not how it will do it.

1.1 Document Purpose

This System Requirements document serves as the second in a series of engineering documents intended to describe the TIMMA AVS Pilot Project, building upon the Concept of Operations (ConOps) document. The System Requirements document describes a set of requirements that, when realized, will satisfy the expressed needs of the facility. This document includes the identification, organization, and presentation of the requirements for the TIMMA AVS Pilot Project, which is made up of various components and features. These requirements are derived from the user needs, constraints, and interfaces that the facility is expected to implement. This System Requirements document addresses conditions for incorporating operational concepts, design constraints, and design configuration requirements as well as the necessary characteristics and quality of individual requirements and the set of all requirements.

This document contains the following chapters:

1. **Chapter 1. Introduction** provides an overview of the key project elements that guide the development of this System Requirements document, including an overview of the project, the stakeholders, requirements development process, and referenced materials.

2. **Chapter 2. System Description** focuses on describing and extending the TIMMA AVS Pilot Project system concepts established in the ConOps, including system capabilities, conditions, constraints, and decomposing the system into its functional groups for establishing requirements.

3. **Chapter 3. System Requirements** contains the requirements for each functional group that make up the system.

4. **Chapter 4. Engineering Principles** provides a description of engineering principles applied to the system and requirements definition process.

1.2 Reference Documents

The following documents form a part of this document to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this document, this document shall be considered the superseding requirement.

1.3 Government Documents

- 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design
- California Manual on Uniform Traffic Control Devices 2014 Rev 5
- Systems Engineering Guide for Intelligent Transportation Systems, Version 3.0, USDOT

1.4 Nongovernment Documents

Nongovernment documents may include:

- Treasure Island Community Development, LLC – Treasure Island Transportation Implementation Plan (TITIP)
- Concept of Operations for TIMMA AVS Pilot Project

2 System Description

2.1 System Definition

The proposed system includes an AVS, supporting AVS management system, charging/maintenance facility, and their interfaces among each other and with the passengers and road users. Refer to project ConOps for the detailed description of the proposed system.

This document proposes functional and non-functional requirements for the system to be developed and tested. These requirements are generated solely for the system created within this project and are not intended to be prescriptive for AVS developed outside the project.

2.2 User Characteristics

This section defines the stakeholders, users, and their roles and responsibilities for the TIMMA AV Shuttle Pilot Project. Stakeholders refers to an individual or organization affected by the activities, inputs and outputs of the system being developed. They may have a direct or indirect interest in the system and their level of participation may vary. This includes public agencies, private organizations or the traveling public (end users) with a vested interest or "stake" in one or more aspects of the TIMMA AV Shuttle Pilot Project as identified in **Table 1: TIMMA AV Shuttle Pilot Stakeholders** and Users. Users are classified based on their perception of the system and the needs identified. Note that some key personnel may serve in multiple roles based on the user needs and functions.

Table 1: TIMMA AV Shuttle Pilot Stakeholders and Users

Target Stakeholders	Users			
	AVS Passengers	**AVS Management System**	**Operations Staff**	**Emergency Vehicle / Operator**
TI/YBI Residents	X			
TI/YBI Visitors	X			
AVS Vendor and Operator		X	X	
Law Enforcement				X
Emergency Medical Services				X
Fire and Rescue				X
Towing Agencies				X

Source: SFCTA

2.2.1 AVS Passengers

AVS Passengers are any riders who use the AVS and are not AVS operations staff. AVS Passengers may be TI/YBI residents, visitors, employees. AVS Passengers may also be users who transferred from another mode of transportation (i.e. pedestrians, bicyclists, shuttle passengers, etc.).

2.2.2 AVS Management System Administrators

AVS Management System users are those who oversee the operations of the shuttle. The AVS Management System users are remote users who may work in the maintenance facility or offsite in a remote operations center.

2.2.3 Operations Staff

AVS Operations Staff users are those who operate the shuttle (i.e. the on-board Operator). These users are located on the AVS but are not considered an AVS Passenger.

2.2.4 Emergency Vehicle / Operator

Emergency Vehicle / Operator users are any users who belong to an emergency response team. These users could be law enforcement, emergency medical services, fire and rescue, and towing agencies. The users may need to access the AVS in the event of an emergency but would not be considered AVS Passengers or Operations Staff.

2.3 Policies and Constraints

The system constraints limit the activities that can be performed during the pilot. The system is constrained by the available budget, the changing environment on TI/YBI, the controlled land use of TI/YBI, and the changing technology landscape.

The available budget limits the duration of the pilot. The pilot is anticipated to last three months. Due to the high fixed cost of deploying the pilot, the variable cost of extending the pilot duration is relatively low to the three-month duration cost.

The changing environment on TI/YBI will affect how well the AVS must perform in work zones. The AVS must be able to perform well in environments that are continuously changing, with both changing lane configurations and surrounding benchmarks like buildings and trees. The AVS or on-board Operator will need to respond to temporary signage and traffic control officers accordingly. In addition, the AVSs will be traveling on roads with mixed-traffic, and even in cases where the roads are closed for testing, they will need to be able to detect and respond to traditional regulatory signs.

SFMTA must be consulted on proposed AVS routes and shuttle stops on Treasure Island.

The controlled land use on TI/YBI will constrain the location of charging and maintenance facilities. While vendors may be free to pick their own facility location on other projects, Treasure Island Development Authority (TIDA) will provide the vendor with facility options.

Automated vehicle technologies are an emerging field and the technology is still under development. There are various plans, guidance, policies, and procedures that have been adopted, published, or currently within rulemaking that govern the use of autonomous vehicles in the state of California and the United States. These include:

- Federal Automated Vehicles Policy, published by the United States Department of Transportation (USDOT) and the National Highway Traffic Safety Administration (NHTSA), provides guidance for developing an approach to automated vehicle performance specifications, the roles delegated to states, and current and proposed regulatory tools to maintain safety in this new transportation environment while not restricting technological innovation.
    - Automated Driving Systems: A Vision for Safety 2.0 (ADS 2.0), published by NHTSA, provides USDOT's cornerstone voluntary guidance document for ADS.
    - Preparing for the Future of Transportation (AV 3.0) builds upon ADS 2.0 and expands the scope to provide USDOT framework and multimodal approach to the safe integration of AVs into the Nation's broader surface transportation system.
    - Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0 (AV 4.0) builds upon AV 3.0 and expands the scope to 38 relevant US Government (USG) components that have direct or tangential equities in the safe development and integration of AV technologies. AV 4.0 seeks to ensure a consistent USG approach to AV technologies, and to detail the authorities, research, and investments being made across the USG so that the US can continue to lead AV technologies' research, development, and integration.
    - Automated Vehicles Comprehensive Plan, developed by USDOT, builds upon the principles stated in AV 4.0, advancing the Department's work to prioritize safety while preparing for the future of transportation.
- Federal Motor Vehicle Safety Standards (FMVSS), also developed by NHTSA, regulate features required for motor vehicles operated on public roads, in categories such as crash avoidance, crashworthiness, and post-crash survivability. Some AVS must receive FMVSS exemptions to operate on public roads.
- The State of California has passed legislation that allows autonomous vehicles that comply with FMVSS to operate on public roadways if a CA DMV permit is issued.
- The California Public Utilities Commission has authorized two pilot programs to test the private prearranged transportation of passengers and has also issued regulations for

the Phase I deployment of AV passenger services. The AVS vendor will need the appropriate California Public Utilities Commission permit prior to providing passenger service. .

The AVS vendor must comply with FMVSS or seek a federal exemption. The vendor must also obtain the appropriate testing permits from the state for testing on public roads and for providing passenger service. These existing regulations and any potential changes or opportunities for exemptions will continue to be monitored by the vendor during the pilot.

3 Requirements

This section of the document lists the identified requirements for TIMMA AVS Pilot Project. The requirements are organized first by requirement type, then by system and services.

The requirements tables in this section include a column for the requirement identifier, user need ID, functional group, description, priority, and verification method:

- The first columns, Requirements Identify, includes a requirement identifier to provide traceability through other documents.
- The second column, User Needs, identifies traceability to user needs, use cases, and/or policies and constraints. The Requirements that doesn't address the identified User Needs directly but addresses the use cases, policies, and constraints, are labeled Not Application (NA).
- The third column, Functional Group, provides the functional group. This is intended to organize the requirements in a manner that allows similar requirements to be grouped together. The following functional groups are considered:
    - Vehicle Control Automation
    - Vehicle System Executive
    - Vehicle System Monitoring and Diagnostics
    - AVS Electric Charging Assist
    - Vehicle Emergency Notification
    - Vehicle Intersection Warning
    - Vehicle Location Determination
    - Vehicle Map Management
    - Vehicle Situation Data Monitoring
    - AVS Roadside Information Reception
    - Fixed-Route Operations
    - Center Vehicle Tracking
    - AVS Schedule Management
    - Center Passenger Counting
    - AVS Passenger Counting
    - Center Security
    - AVS Security
    - Center Information Services
    - AVS On-Board Information Services
    - Center Multi-modal Coordination
    - AVS On-Board Trip Monitoring
    - Garage Maintenance
    - AVS On-Board Maintenance
    - AVS Pedestrian Safety
    - AVS Boarding/Alighting
    - AVS V2V Safety
    - AVS On-Board Fare Management
    - AVS Center Fare Management
    - AVS Performance Improvement
    - AVS Operations
    - Operations
    - Vehicle
    - Transportation
    - Storage
    - Data

- The fourth column, Description, provides the requirement description, which is intended to be well-formed as specified by the *Systems Engineering Guide for Intelligent Transportation Systems*[1]: necessary, clear, complete, correct, feasible, and verifiable.
- The fifth column, Priority, identifies the requirements priorities. The essential priorities are anticipated to be implemented for the pilot. The Desirable priority identifies those requirements which are desirable for future deployments. However, if the vendor can meet the desirable priorities, the vendor may choose to implement and test as part of the pilot project.
- The last column, Verification Method, provides the verification method – the four fundamental verification methods considered include: inspection, demonstration, test, and analysis. Definitions of these methods are provided in Methods of Verification in Chapter 4. Engineering Principles.

Table 2: List of Requirement Types describes the classifications of the requirements in this document.

Table 2: List of Requirement Types

Type	Description
Functional (FN)	The Functional requirements specify actionable and qualitative behaviors (e.g. functions, tasks) of the core system of interest, which in the case of TIMMA AVS Pilot Project.
Operational Requirements (OR)	The Operational requirements are capabilities that are desired to address mission area deficiencies, evolving applications or threats, emerging technologies, or system cost improvements.
Performance (PR)	The Performance requirements specify quantifiable characteristics that define the extent, or how well, and under what conditions, a function or task is to be performed (e.g. rates, velocities).
Non-Functional (NF)	The Non-Functional requirements define the characteristics of the overall operation of the system, including the following: • **Physical (PY)** – specifies the construction, durability, adaptability, and environmental characteristics of the system • **Availability and Recovery (AR)** – define the times of day, days of year, and overall percentage the system can be used and when it will not be available for use as well as recovery point and time objectives. • **Maintainability (MT)** – specify the level of effort required to locate and correct an error during operation.

[1] https://www.fhwa.dot.gov/cadiv/segb/files/segbversion3.pdf

	• **Storage and Transport (ST)** – specify the physical location and environment for the system, including designated storage facility, installation site, repair facility, requirements for transporting equipment, etc.
Data Requirements	The Data Requirements specify the data that are anticipated to be collected as part of the pilot.
ADA Requirements	The ADA Requirements specific the requirements that needs to be satisfied as part of the vendor's compliance with ADA Act of 1990.

Source: SFCTA

3.1 System Requirements

This section itemizes the requirements associated with each of the system's capabilities. A "function" is defined as a group of related requirements. TIMMA AVS Pilot Project's system requirements correspond to the project's various components.

3.1.1 Functional Requirements

This section provides the high-level requirements for the system of interest (i.e. what the system will do). The requirements in **Table 3: Functional Requirements** are organized by the functional groups and are related to the user needs documented in the project ConOps.

Table 3: Functional Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-001-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall monitor the area behind and in front of the AVS to determine the proximity of other objects to the AVS.	Essential	Demonstration
AVS-FN-VOC-002-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall monitor the area to the sides of the AVS to determine the proximity of other objects to the AVS to determine if a control adjustment is needed.	Essential	Demonstration
AVS-FN-VOC-003-v01	AVS-UN016-v01	Vehicle Control Automation	The AVS shall detect, understand and comply with regulatory signs.	Essential	Demonstration
AVS-FN-VOC-004-v01	AVS-UN016-v01	Vehicle Control Automation	The AVS shall understand and comply with speed laws.	Essential	Demonstration
AVS-FN-VOC-005-v01	AVS-UN016-v01	Vehicle Control Automation	The AVS shall detect and understand pavement markings, and be able to operate on streets without clear lane markings.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-006-v01	AVS-UN016-v01	Vehicle Control Automation	The AVS shall detect and understand the directions providing by human traffic control officers, either through the driving system, safety driver, or remote operator, or any combination of these.	Essential	Demonstration
AVS-FN-VOC-007-v01	AVS-UN016-v01 AVS-UN045-v01	Vehicle Control Automation	The AVS shall detect, understand, and comply with traffic signals.	Essential	Demonstration
AVS-FN-VOC-008-v01	AVS-UN02-v01	Vehicle Control Automation	The AVS shall arbitrate between detector concurrent regulatory signs, pavement markings, traffic signs, and object detections.	Essential	Demonstration
AVS-FN-VOC-009-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall provide its location with lane-level accuracy to on-board control automation applications.	Essential	Demonstration
AVS-FN-VOC-010-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall determine the status of host vehicle systems including AVS speed, heading, yaw, wheelspin, ABS, traction control, and wiper status. (host vehicle refers to the originator of a vehicular transmission of information).	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-011-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall determine a potentially hazardous road condition.	Essential	Demonstration
AVS-FN-VOC-012-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall calculate AVS paths to determine if an impending collision is detected.	Essential	
AVS-FN-VOC-013-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall evaluate the likelihood of a collision between two vehicles or a AVS and a stationary object, based on the proximity of other objects to the AVS, roadway characteristics, and the current speed and direction of the AVS.	Essential	Demonstration
AVS-FN-VOC-014-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall provide position control adjustments.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-015-v01	AVS-UN017-v01 AVS-UN018-v01 AVS-UN022-v01 AVS-UN037-v01	Vehicle Control Automation	The AVS shall provide an interface through which an Operator can initiate, monitor, and terminate automatic control of the AVS.	Essential	Demonstration
AVS-FN-VOC-016-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall be capable of performing control actions based upon warnings received regarding pedestrians, cyclists, and other non-motorized and motorized users that are sharing the roadway with the AVS.	Essential	Demonstration
AVS-FN-VOC-017-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS should be capable of performing control actions based upon information received from the infrastructure regarding the status of the intersection the AVS is approaching.	Desirable	Demonstration
AVS-FN-VOC-018-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall automatically perform pre-crash actions, including seatbelt tightening, brake assist, airbag pre-arming, bumper raising/extension.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-019-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall take speed control actions (e.g., throttle, brakes).	Essential	Demonstration
AVS-FN-VOC-020-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall take steering control actions.	Essential	Demonstration
AVS-FN-VOC-021-v01	AVS-UN015-v01 AVS-UN019-v01	Vehicle Control Automation	The AVS shall present AVS control information to the Operator in audible or visual forms without impairing the Operator's ability to control the AVS in a safe manner.	Essential	Demonstration
AVS-FN-VOC-022-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall analyze its own applications' performance and enter fail-safe mode (a mode such that the application cannot provide information or perform actions that affect its host) when critical components fail.	Essential	Demonstration
AVS-FN-VOC-023-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall notify the Operator when onboard components or safety applications are offline.	Essential	Demonstration
AVS-FN-VOC-024-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall collect and monitor data concerning the safety of the AVS - including, steering, braking, acceleration, emissions, fuel economy, engine performance, etc.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VOC-025-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall determine the status of the AVS in terms of its continued ability to operate in a safe manner.	Essential	Demonstration
AVS-FN-VOC-026-v01	AVS-UN020-v01	Vehicle Control Automation	The AVS shall provide warnings to the Operator of potential dangers based on sensor input and analysis concerning the safety of the AVS.	Essential	Demonstration
AVS-FN-VOC-027-v01	AVS-UN023-v01	Vehicle Control Automation	The AVS shall be able to determine when it is uncertain regarding which action to take.	Essential	Demonstration
AVS-FN-VOC-028-v01	AVS-UN023-v01	Vehicle Control Automation	The AVS shall decrease speed and pull over in a legal stopping location, if safe, when it determines uncertainty regarding which action to take.	Essential	Demonstration
AVS-FN-VSE-001-v01	AVS-UN013-v01	Vehicle System Executive	The AVS shall manage the overall device software configuration and operation and support configuration management, computer resource management, and govern software installation and upgrade.	Essential	Demonstration
AVS-FN-VSE-002-v01	AVS-UN013-v01	Vehicle System Executive	The AVS shall allow a service center to remotely install or upgrade software in the AVS. Security of this data exchange shall be addressed in the vendor’s Security/Data Management Plan.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VSE-003-v01	AVS-UN013-v01	Vehicle System Executive	The AVS shall provide the capability for an Operator to update the configuration of software or hardware in the AVS.	Essential	Demonstration
AVS-FN-VSM-001-v01	AVS-UN020-v01 AVS-UN032-v01	Vehicle System Monitoring and Diagnostics	The AVS shall be able to monitor on-board sensors to determine the operating conditions of on-board systems critical to safe and efficient operation of the AVS.	Essential	Demonstration
AVS-FN-VSM-002-v01	AVS-UN020-v01	Vehicle System Monitoring and Diagnostics	The AVS shall be capable of performing diagnostic tests using on-board data to identify problems in AVS system operation and to determine possible causes of the problems.	Essential	Demonstration
AVS-FN-VSM-003-v01	AVS-UN020-v01	Vehicle System Monitoring and Diagnostics	The AVS shall be capable of providing diagnostic information regarding on-board systems to the Operator.	Essential	Demonstration
AVS-FN-VSM-004-v01	AVS-UN032-v01	Vehicle System Monitoring and Diagnostics	The AVS Management System shall monitor the status of AVSs.		
AVS-FN-ECA-001-v01	AVS-UN033-v01	AVS Electric Charging Assist	The AVS shall be able to provide the operational status of the electrical system, the charging capacity and charging rate for the AVS, and % charge complete to an electric charging station.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-ECA-002-v01	AVS-UN031-v01	AVS Electric Charging Assist	The AVS shall maintain power throughout the operational period.	Essential	Demonstration
AVS-FN-VEM-001-v01	AVS-UN034-v01	Vehicle Emergency Notification	The AVS shall provide the capability for an Operator to report an emergency and summon assistance.	Essential	
AVS-FN-VEM-002-v01	AVS-UN004-v01	Vehicle Emergency Notification	The AVS shall provide the capability to accept input from an Operator, passengers or emergency responders via a panic button or some other functionally similar form of input device provided as part of the in-vehicle equipment.	Essential	Demonstration
AVS-FN-VEM-003-v01	AVS-UN034-v01	Vehicle Emergency Notification	The AVS shall acknowledge the Operator's request for emergency assistance.	Essential	Demonstration
AVS-FN-VEM-004-v01	AVS-UN034-v01	Vehicle Emergency Notification	The AVS shall collect AVS operational state and all sensor information from the host vehicle.	Essential	Demonstration
AVS-FN-VEM-005-v01	AVS-UN034-v01	Vehicle Emergency Notification	The AVS shall determine if the host vehicle has been involved in a collision.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VEM-006-v01	AVS-UN034-v01	Vehicle Emergency Notification	The AVS should forward a request for assistance to AVS Management System containing the AVS's current location, its identity and basic vehicle data relevant to its current condition, as well as any other data, such as AVS orientation, etc., that may be developed in-vehicle by other systems.	Desirable	Demonstration
AVS-FN-VIW-001-v01	AVS-UN015-v01 AVS-UN019-v01 AVS-UN019-v01	Vehicle Intersection Warning	The AVS shall provide AVS path information to identify if AVS is performing an unpermitted movement at an intersection such as a stop sign violation.	Essential	Demonstration
AVS-FN-VIW-002-v01	AVS-UN045-v01	Vehicle Intersection Warning	The AVS should be able to receive intersection signal timing information from roadside infrastructure for the AVS to determine if it will safely cross the intersection given its current location and speed.	Desirable	Demonstration
AVS-FN-VIW -003-v01	AVS-UN045-v01	Vehicle Intersection Warning	The AVS should be able to receive warning from the infrastructure if an intersection violation appears to be imminent.	Desirable	Demonstration
AVS-FN-VLD-001-v01	AVS-UN015-v01	Vehicle Location Determination	The AVS shall provide the AVS's current location to other in-vehicle functions.	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VLD-002-v01	AVS-UN015-v01	Vehicle Location Determination	The AVS shall calculate the location from one or more data sources including positioning systems such as GPS, sensors that track AVS movement, and maps used to determine the likely AVS route.	Essential	Analyze
AVS-FN-VLD-003-v01	AVS-UN015-v01	Vehicle Location Determination	The AVS should obtain position correction data from the Connected Vehicle Roadside Equipment.	Desirable	Analyze
AVS-FN-VLD-004-v01	AVS-UN015-v01	Vehicle Location Determination	The AVS shall apply position correction data to its base positional data.	Essential	Analyze
AVS-FN-VMP-001-v01	AVS-UN027-v01	Vehicle Map Management	The AVS shall make basemap, roadway geometry, intersection geometry and parking facility geometry information available to other onboard vehicle applications.	Essential	Analyze
AVS-FN-VMP-002-v01	AVS-UN027-v01	Vehicle Map Management	The AVS should provide its location to AVS Management System.	Desirable	Analyze
AVS-FN-VMP-003-v01	AVS-UN027-v01	Vehicle Map Management	The AVS should obtain basemap updates from AVS Management System.	Desirable	Analyze
AVS-FN-VMP-004-v01	AVS-UN027-v01	Vehicle Map Management	The AVS should obtain roadway geometry information from AVS Management System.	Desirable	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-VMP-005-v01	AVS-UN027-v01	Vehicle Map Management	The AVS should obtain intersection geometry information from AVS Management System.	Desirable	Demonstration
AVS-FN-SDM-001-v01	AVS-UN030-v01	Vehicle Situation Data Monitoring	The AVS shall receive data collection parameters from AVS Management System.	Essential	Demonstration
AVS-FN-SDM-002-v01	AVS-UN030-v01	Vehicle Situation Data Monitoring	The AVS shall provide traffic-related data including snapshots of measured speed and heading and events including starts and stops, speed changes, and other vehicle control.	Essential	Demonstration
AVS-FN-SDM-003-v01	AVS-UN030-v01	Vehicle Situation Data Monitoring	The AVS shall provide data to AVS Management System in accordance with data collection parameters provided.	Essential	Demonstration
AVS-FN-SMA-001-v01	AVS-UN030-v01	Vehicle Speed Management Assist	The AVS shall travel at speed appropriate for the real-time road conditions (shall not exceed posted speed at any time).	Essential	Demonstration
AVS-FN-RIR-001-v01	AVS-UN016-v01	AVS Roadside Information Reception	The AVS shall present to the Operator a visual display of static sign information or dynamic roadway conditions information.	Essential	Demonstration
AVS-FN-FRO-001-v01	AVS-UN027-v01	Fixed-Route Operations	The AVS Management System shall provide the interface to the system Operator to control the generation of new routes and schedules.	Desirable	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-FRO-002-v01	AVS-UN027-v01	Fixed-Route Operations	The AVS Management System shall dispatch fixed route AVS.	Essential	Demonstration
AVS-FN-FRO-003-v01	AVS-UN038-v01	Fixed-Route Operations	The AVS Management System shall consult with SFMTA on the generation of routes and schedules.	Essential	Demonstration
AVS-FN-FRO-004-v01	AVS-UN027-v01 AVS-UN046-v01	Fixed-Route Operations	The AVS Management System shall receive information from SFCTA concerning work zones, roadway conditions, weather conditions, incidents, asset restrictions, work plans, etc. for use in scheduling.	Essential	Demonstration
AVS-FN-FRO-005-v01	AVS-UN051-v01	Fixed-Route Operations	The AVS Management System shall disseminate up-to-date schedules and route information to SFMTA.	Essential	Demonstration
AVS-FN-FRO-006-v01	AVS-UN009-v01	Fixed-Route Operations	The AVS Management System should provide an interface to the archive data repository to enable the SFCTA to retrieve historical operating data for use in planning AVS routes and schedules.	Desirable	Demonstration
AVS-FN-FRO-007-v01	AVS-UN029-v01	Fixed-Route Operations	The AVS Management System shall monitor AVS schedule adherence to manage AVS operations.	Essential	Demonstration
AVS-FN-CVT-001-v01	AVS-UN029-v01	Center Vehicle Tracking	The AVS Management System shall monitor the locations of all AVS within its network.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-CVT-002-v01	AVS-UN029-v01	Center Vehicle Tracking	The AVS Management System shall determine adherence of AVSs to their assigned schedule.	Essential	Demonstration
AVS-FN-ASM-001-v01	AVS-UN029-v01	AVS Schedule Management	The AVS shall receive a vehicle assignment including shuttle route information, and shuttle service instructions for the Operator.	Essential	Demonstration
AVS-FN-ASM-002-v01	AVS-UN029-v01	AVS Schedule Management	The AVS shall determine the deviation from the predetermined schedule.	Essential	Demonstration
AVS-FN-ASM-003-v01	AVS-UN029-v01	AVS Schedule Management	The AVS shall calculate the estimated times of arrival (ETA) at shuttle stops.	Essential	Demonstration
AVS-FN-ASM-004-v01	AVS-UN043-v01	AVS Schedule Management	The AVS should determine scenarios to correct the schedule deviation.	Desirable	Demonstration
AVS-FN-ASM-005-v01	AVS-UN043-v01	AVS Schedule Management	The AVS should provide the schedule deviations and instructions for schedule corrections to the AVS Operator.	Desirable	Demonstration
AVS-FN-ASM-006-v01	AVS-UN029-v01	AVS Schedule Management	The AVS should send the schedule deviation and estimated arrival time information to the AVS Management System.	Desirable	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-ASM-007-v01	AVS-UN028-v01	AVS Schedule Management	The AVS shall notify the AVS Management System of AVS location and operational status as the AVS exits and returns to the Maintenance/storage facility to support future AVS assignments.	Essential	Demonstration
AVS-FN-APC-001-v01	AVS-UN009-v01	AVS Passenger Counting	The AVS shall count passengers boarding and alighting.	Essential	Demonstration
AVS-FN-APC-002-v01	AVS-UN009-v01	AVS Passenger Counting	The passenger counts shall be related to location to support association of passenger counts with routes, route segments, or shuttle stops.	Essential	Demonstration
AVS-FN-APC-003-v01	AVS-UN009-v01	AVS Passenger Counting	The passenger counts shall be timestamped so that ridership can be measured by time of day and day of week.	Essential	Demonstration
AVS-FN-APC-004-v01	AVS-UN009-v01	AVS Passenger Counting	The AVS shall send the collected passenger count information to the AVS Management System.	Essential	Demonstration
AVS-FN-CPC-001-v01	AVS-UN009-v01	Center Passenger Counting	The AVS Management System shall collect passenger count information from each AVS.	Essential	Demonstration
AVS-FN-CPC-002-v01	AVS-UN009-v01	Center Passenger Counting	The AVS Management System shall calculate shuttle ridership data by route, route segment, shuttle stop, time of day, and day of week based on the collected passenger count information.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-CPC-003-v01	AVS-UN009-v01	Center Passenger Counting	The AVS Management System shall provide compiled ridership data available to the SFCTA.	Essential	Demonstration
AVS-FN-CSE-001-v01	AVS-UN014-v01	Center Security	The AVS Management System shall monitor AVS operational data to determine if the AVS is off-route and assess whether a security incident is occurring.	Essential	Demonstration
AVS-FN-CSE-002-v01	AVS-UN014-v01	Center Security	The AVS Management System shall receive reports of emergencies on-board AVSs entered directly by the AVS Operator or from a traveler through interfaces such as panic buttons or alarm switches.	Essential	Demonstration
AVS-FN-CSE-003-v01	AVS-UN014-v01	Center Security	The AVS Management System authenticate AVS Operators.	Essential	Demonstration
AVS-FN-CSE-004-v01	AVS-UN014-v01	Center Security	The AVS Management System shall provide shuttle incident information along with other service data to emergency centers.	Essential	Demonstration
AVS-FN-CSE-005-v01	AVS-UN014-v01	Center Security	The AVS Management System shall receive information pertaining to a wide-area alert such as weather alerts, disaster situations, or child abductions.	Essential	Demonstration
AVS-FN-CSE-006-v01	AVS-UN034-v01	Center Security	The AVS Management System shall send wide-area alert information to travelers (on-board AVS).	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-CSE-007-v01	AVS-UN034-v01	Center Security	The AVS Management System shall notify the response to cybersecurity incidents involving the shuttle including notifying Emergency Management, SFCTA and SFMTA.	Essential	Demonstration
AVS-FN-CSE-007-v01	AVS-UN034-v01	Center Security	The AVS Management System should be able to remotely disable (or reset the disabling of) a AVS in service.	Desirable	Demonstration
AVS-FN-ASE-001-v01	AVS-UN014-v01	AVS Security	The AVS shall perform video and audio surveillance inside of AVSs and output raw video or audio data for local monitoring (for processing or direct output to the AVS Operator). Surveillance must comply with the City's Privacy First and Surveillance policies.	Essential	Demonstration
AVS-FN-ASE-002-v01	AVS-UN014-v01	AVS Security	The AVS shall perform video and audio surveillance inside of AVSs and output raw video or audio data for remote monitoring.	Essential	Demonstration
AVS-FN-ASE-003-v01	AVS-UN014-v01	AVS Security	The AVS shall perform video and audio surveillance inside of AVSs and output raw video or audio data for local storage (e.g., in an event recorder).	Essential	Demonstration
AVS-FN-ASE-004-v01	AVS-UN014-v01	AVS Security	The AVS shall monitor and output surveillance and sensor equipment status and fault indications.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-ASE-005-v01	AVS-UN014-v01	AVS Security	The AVS shall receive acknowledgments of the emergency request from the AVS Management System and output this acknowledgment to the AVS Operator or to the travelers.	Essential	Demonstration
AVS-FN-ASE-006-v01	AVS-UN014-v01	AVS Security	The AVS shall be capable of receiving an emergency message for broadcast to the travelers or to the AVS Operator.	Essential	Demonstration
AVS-FN-ASE-007-v01	AVS-UN037-v01	AVS Security	The AVS shall be capable of being disabled or enabled based on commands from the authentic inputs from the AVS Operator.	Essential	Demonstration
AVS-FN-ASE-008-v01	AVS-UN003-v01	AVS Security	The AVS shall perform authentication of the AVS Operator.	Essential	Demonstration
AVS-FN-CIS-001-v01	AVS-UN003-v01	Center Information Services	The AVS Management System shall exchange shuttle schedules, real-time arrival information, and general shuttle service information with SFMTA to support transit traveler information systems.	Essential	Demonstration
AVS-FN-CIS-002-v01	AVS-UN003-v01	Center Information Services	The SFCTA shall provide AVS advisory data, including alerts and advisories pertaining to major emergencies, or man-made disasters.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-AIS-001-v01	AVS-UN003-v01	AVS On-Board Information Services	The AVS should enable traffic and travel advisory information to be requested and output to the traveler. Such information may include shuttle routes, status, schedules, real-time schedule adherence.	Desirable	Demonstration
AVS-FN-AIS-002-v01	AVS-UN003-v01	AVS On-Board Information Services	The AVS shall broadcast advisories about the imminent arrival of the AVS at the next stop via an on-board automated annunciation system.	Essential	Demonstration
AVS-FN-AIS-003-v01	AVS-UN003-v01 AVS-UN006-v01	AVS On-Board Information Services	The AVS shall support input and output forms that are suitable for travelers with physical disabilities.	Essential	Demonstration
AVS-FN-AIS-004-v01	AVS-UN003-v01	AVS On-Board Information Services	The AVS shall gather advisory data, including alerts and advisories pertaining to major emergencies, or man-made disasters.	Essential	Demonstration
AVS-FN-AIS-005-v01	AVS-UN003-v01	AVS On-Board Information Services	The AVS shall tailor the output of the request traveler information based on the current location of the AVS.	Essential	Demonstration
AVS-FN-CMM-001-v01	AVS-UN044-v01	Center Multi-modal Coordination	The AVS Management System should coordinate with other transportation providers on schedules and services.	Desirable	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-CMM-002-v01	AVS-UN044-v01	Center Multi-modal Coordination	The AVS Management System should share transfer cluster and transfer point information with other transit centers. A transfer cluster is a collection of stop points, stations, or terminals where transfers can be made conveniently.	Desirable	Demonstration
AVS-FN-ATM-001-v01	AVS-UN001-v01 AVS-UN002-v01 AVS-UN007-v01 AVS-UN008-v01	AVS On-Board Trip Monitoring	The AVS shall support the computation of the location of a AVS using on-board sensors to augment the location determination function. This may include proximity to the shuttle stops or other known reference points as well as recording trip length.	Essential	Demonstration
AVS-FN-ATM-002-v01	AVS-UN038-v01	AVS On-Board Trip Monitoring	The AVS shall record shuttle trip monitoring data including vehicle mileage and electric charge.	Essential	Demonstration
AVS-FN-ATM-003-v01	AVS-UN038-v01	AVS On-Board Trip Monitoring	The AVS shall record shuttle trip monitoring data including operational status information such as doors open/closed, running times, etc.	Essential	Demonstration
AVS-FN-ATM-004-v01	AVS-UN030-v01	AVS On-Board Trip Monitoring	The AVS shall send the AVS trip monitoring data to AVS Management System-based trip monitoring functions.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-ATM-005-v01	AVS-UN001-v01 AVS-UN002-v01	AVS On-Board Trip Monitoring	The AVS shall stop at all designated shuttle stops.	Essential	Demonstration
AVS-FN-ATM-006-v01	AVS-UN007-v01 AVS-UN008-v01	AVS On-Board Trip Monitoring	The AVS should receive (and act upon) requests from travelers to stop at designated shuttle stop.	Desirable	Demonstration
AVS-FN-CGM-001-v01	AVS-UN038-v01	Garage Maintenance	The Maintenance/Storage Facility shall collect operational and maintenance data from AVS.	Desirable	Demonstration
AVS-FN-CGM-002-v01	AVS-UN013-v01	Garage Maintenance	The Maintenance/Storage Facility shall monitor the condition of a AVS to analyze brake, drive train, sensors, battery charge, steering, tire, processor, communications equipment, and AVS mileage to identify mileage based maintenance, out-of-specification or imminent failure conditions.	Essential	Demonstration
AVS-FN-CGM-003-v01	AVS-UN013-v01	Garage Maintenance	The Maintenance/Storage Facility shall generate AVS maintenance schedules that identify the maintenance or repair to be performed and when the work is to be done.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-CGM-004-v01	AVS-UN013-v01	Garage Maintenance	The Maintenance/Storage Facility shall verify that the AVS maintenance activities were performed correctly, using the AVS's status, the maintenance personnel's work assignment, and the AVS maintenance schedules.	Essential	Demonstration
AVS-FN-CGM-005-v01	AVS-UN013-v01	Garage Maintenance	The Maintenance/Storage Facility shall generate a time-stamped maintenance log of all maintenance activities performed on an AVS.	Essential	Demonstration
AVS-FN-CGM-006-v01	AVS-UN013-v01	Garage Maintenance	The Maintenance/Storage Facility shall provide AVS operations personnel with the capability to update AVS maintenance information and receive reports on all AVS operations data.	Essential	Demonstration
AVS-FN-OBM-001-v01	AVS-UN038-v01	AVS On-Board Maintenance	The AVS shall collect and process AVS mileage data from the sensors on-board.	Essential	Demonstration
AVS-FN-OBM-002-v01	AVS-UN038-v01	AVS On-Board Maintenance	The Maintenance/Storage Facility shall collect and process the AVS's operating conditions such as engine temperature, brake wear, internal lighting, environmental controls, etc.	Essential	Demonstration
AVS-FN-APS-001-v01	AVS-UN015-v01	AVS Pedestrian Safety	The AVS shall determine if pedestrians are near an AVS.	Essential	Demonstration
AVS-FN-APS-002-v01	AVS-UN015-v01	AVS Pedestrian Safety	The AVS shall determine if pedestrians are at risk of crash due to proximity of AVS.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-APS-003-v01	AVS-UN015-v01	AVS Pedestrian Safety	The AVS shall take appropriate actions to prevent collision.	Essential	Demonstration
AVS-FN-APS-004-v01	AVS-UN011-v01	AVS Pedestrian Safety	The AVS shall make itself visible with lights.	Essential	Demonstration
AVS-FN-APS-005-v01	AVS-UN011-v01	AVS Pedestrian Safety	The AVS shall emit an alert sound to warn pedestrians of the shuttle's presence.		Demonstration
AVS-FN-ABA-001-v01	AVS-UN039-v01 AVS-UN040-v01	AVS Boarding/Alighting	The AVS should determine when its position is near a shuttle station/stop.	Desirable	Demonstration
AVS-FN-ABA-002-v01	AVS-UN039-v01 AVS-UN040-v01	AVS Boarding/Alighting	The AVS should determine whether pedestrians are at AVS stops.	Desirable	Demonstration
AVS-FN-ABA-003-v01	AVS-UN039-v01 AVS-UN040-v01	AVS Boarding/Alighting	The AVS should stop at the designated shuttle stop (if pedestrians are present).	Desirable	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-FN-AVS-001-v01	AVS-UN001-v01 AVS-UN002-v01	AVS V2V Safety	The AVS shall provide to other vehicles an audio and/or visual indication of its intent to leave a designated shuttle stop.	Essential	Demonstration
AVS-FN-AVS-002-v01	AVS-UN001-v01 AVS-UN002-v01	AVS V2V Safety	The AVS shall take appropriate action if a collision threat exists as it prepares to leave a stop or station.	Essential	Demonstration
AVS-FN-AVS-003-v01	AVS-UN001-v01 AVS-UN002-v01	AVS V2V Safety	The AVS shall be able to identify if another vehicle is pulling in front of it to make a right turn using its sensors that can detect the location of other vehicles.	Essential	Demonstration
AVS-FN-AFM-001-v01	AVS-UN041-v01	AVS On-Board Fare Management	The AVS should support payment for shuttle fares.	Desirable	Demonstration
AVS-FN-CFM-001-v01	AVS-UN041-v01	AVS Center Fare Management	The AVS Management System should support the payment of shuttle fare transactions.	Desirable	Demonstration
AVS-FN-AFM-001-v01	AVS-UN043-v01	AVS Performance Improvement	The AVS Management System should optimize route operations and minimize passenger travel time by limiting dwell times and maintaining consistent headways on its route.	Desirable	Demonstration

3.1.2 Operational Requirements

Table 4. Operational Requirements below identifies the AVS operational requirements for the project.

Table 4. Operational Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-OPS-001-v01	AVS-UN012-v01 AVS-UN042-v01	Operations	The Operator shall be responsible for keeping the AVS charged/fueled for the duration of the daily service period.	Essential	Demonstration
AVS-OP-OPS-002-v01	AVS-UN012-v01	Operations	The charging/fueling shall be able to be performed manually.	Essential	Demonstration
AVS-OP-OPS-003-v01	AVS-UN042-v01	Operations	The AVS should be able to automatically connect to a charging/fueling source independently of human assistance from the operations staff.	Desirable	Demonstration
AVS-OP-OPS-004-v01	AVS-UN005-v01	Operations	The Operator shall always remain within the AVS while in operation and shall be responsible for greeting and assisting guests.	Essential	Inspection
AVS-OP-OPS-005-v01	AVS-UN035-v01	Operations	The Operator within the AVS always shall be responsible for taking control of the AVS, if necessary. (Greeting role and the taking control roles may be played by the same person.)	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-OPS-006-v01	AVS-UN005-v01	Operations	Operator shall have received training from the Vendor to: • Assisting and interacting with passengers, including providing mobility assistance during passenger boarding and alighting, as necessary, and how to properly secure people who use mobility devices • Provide accurate basic information about the AVS, and the purpose of the route • Receive and record passenger feedback • Operate a ramp, door, and/or charging station, if not automated • Road test an AVS • Have a working knowledge of AVS equipment • Perform clean-up, including bodily fluid • Intervene in AVS operations, if necessary • Collect data necessary to evaluate the pilot • Comply with all the training requirements set forth by the DMV and CPUC for both safety drivers and remote operators.	Essential	Verification
AVS-OP-OPS-007-v01	AVS-UN005-v01	Operations	Operators shall be employees, contractors, or agents of the Vendor.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-OPS-008-v01	AVS-UN005-v01	Operations	Operators shall obtain and maintain: • Defensive driving certification • First Aid training • A valid driver's license that is recognized by the State of California • No more than two traffic violations or preventable accidents in the last three years • All necessary permits to operate an autonomous vehicle in the state of California.	Essential	Inspection
AVS-OP-OPS-009-v01	NA	Operations	The Vendor shall be responsible for developing Standard Operating Procedures for the AVSs and Operations staff.	Essential	Inspection
AVS-OP-OPS-010-v01	AVS-UN031-v01	Operations	The Operator shall ensure the AVSs are sufficiently charged or taken out of service early under abnormal conditions after servicing all passengers who are already on board.	Essential	Demonstration
AVS-OP-OPS-011-v01	AVS-UN046-v01	Operations	The Vendor shall monitor local weather patterns.	Essential	Demonstration
AVS-OP-OPS-012-v01	AVS-UN024-v01	Operations	The Vendor shall define and document the operational design domain (ODD) of the AVS. This includes identifying how the AVS will respond when operating outside of it's ODD, or when the ODD changes during daily operations (e.g.: weather-related impacts). The Vendor shall also identify when and how SFCTA will be notified when a vehicle leaves it's ODD.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-OPS-013-v01	AVS-UN046-v01	Operations	The Vendor shall collaboratively work with SFCTA to define an upcoming inclement weather event threshold that would risk placing the shuttle in service when outside its ODD (such as ponding water on the roadway, visibility, or other physical limitations) at which it would suspend or limit operations or shift to manual mode.	Essential	Demonstration
AVS-OP-OPS-014-v01	AVS-UN046-v01	Operations	The Vendor shall notify SFCTA in the event this inclement weather threshold is met.	Essential	Demonstration
AVS-OP-OPS-015-v01	AVS-UN046-v01	Operations	The Vendor shall suspend or limit operations or shift to manual mode when the inclement weather threshold is met.	Essential	Demonstration
AVS-OP-OPS-016-v01	AVS-UN046-v01	Operations	The AVS Management System should be able to monitor local weather patterns and be aware of an approaching severe weather event or other conditions that may impact AVS operations.	Desirable	Demonstration
AVS-OP-OPS-017-v01	AVS-UN046-v01	Operations	The Vendor shall immediately notify SFCTA of any crashes involving any road user or incidents related to passengers.	Essential	Inspection
AVS-OP-OPS-018-v01	AVS-UN046-v01	Operations	The Vendor shall have an incident response plan in the event of an incident.	Essential	Inspection
AVS-OP-VEH-001-v01	NA	Vehicle	The Operator shall ensure sufficient tire pressure and enough tread to safety operate AVS.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-002-v01	AVS-UN001-v01 AVS-UN002-v01	Vehicle	The AVS shall stop and open doors at designated locations to allow passengers to board and alight.	Essential	Demonstration
AVS-OP-VEH-003-v01	AVS-UN001-v01 AVS-UN002-v01	Vehicle	The AVS doors shall have a safety sensitive edge and/or mechanism to open if an object is stuck in the doorway.	Essential	Demonstration
AVS-OP-VEH-004-v01	NA	Vehicle	The AVS shall not park in a spot blocking access to a fire hydrant or crosswalk or any other prohibited location.	Essential	Demonstration
AVS-OP-VEH-005-v01	AVS-UN005-v01	Vehicle	The AVS shall stop and open doors if they have detected that there is an issue on board, through sensors, passenger input, and/or secure override.	Essential	Demonstration
AVS-OP-VEH-006-v01	AVS-UN005-v01	Vehicle	The AVS shall also have multiple secure means of egress, in the event the primary exit is blocked and/or power failure occurs.	Essential	Inspection
AVS-OP-VEH-007-v01	AVS-UN039-v01 AVS-UN040-v01	Vehicle	The AVS should allow passengers to board and alight on-demand at designated stops without stopping at each stop.	Desireable	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-008-v01	AVS-UN041-v01	Vehicle	The AVS may have the ability to collect fares. Fares will not be collected as part of the pilot but could be demonstrated for use in other scenarios where AVSs may be deployed.	Desirable	Demonstration
AVS-OP-VEH-009-v01	AVS-UN003-v01	Vehicle	The AVS shall be capable of providing directional (i.e., eastbound to Avenue B & 9th Street) information in audible and visual form to passengers on both the inside and the outside of the AVS.	Essential	Demonstration
AVS-OP-VEH-010-v01	NA	Vehicle	The AVS shall be able to operate on the public roads as defined above in mixed traffic (integrated with other vehicles, trucks, bicyclists, pedestrians, etc.) without Operator intervention, except in cases of failure or degraded conditions and maintenance conditions. (Refer to ConOps for definition of these conditions.)	Essential	Demonstration
AVS-OP-VEH-011-v01	AVS-UN024-v01	Vehicle	The Vendor shall identify the ability of AVS to operate the following operating functions in automated mode:	Essential	Demonstration
AVS-OP-VEH-011.1-v01	AVS-UN024-v01	Vehicle	Following the specified route.	Essential	Demonstration
AVS-OP-VEH-011.2-v01	AVS-UN024-v01	Vehicle	Pulling over to the side of the road.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-011.3-v01	AVS-UN024-v01	Vehicle	Moving out of the travel lane and stopping to service stop locations.	Essential	Demonstration
AVS-OP-VEH-011.4-v01	AVS-UN024-v01	Vehicle	Performing car following when approaching intersections.	Essential	Demonstration
AVS-OP-VEH-011.5-v01	AVS-UN024-v01	Vehicle	Performing car following in stop and go traffic conditions by maintaining a safe distance behind the vehicle in front of them and determining when to proceed based on that vehicle's behavior.	Essential	Demonstration
AVS-OP-VEH-011.6-v01	AVS-UN024-v01	Vehicle	Navigating unsignalized intersections.	Essential	Demonstration
AVS-OP-VEH-011.7-v01	AVS-UN024-v01	Vehicle	Performing left and right turns.	Essential	Demonstration
AVS-OP-VEH-011.8-v01	AVS-UN024-v01	Vehicle	Entering and emerging from a stop-controlled traffic circle.	Essential	Demonstration
AVS-OP-VEH-011.9-v01	AVS-UN024-v01	Vehicle	Crossing intersections with traffic speed limits up to 35 mph. (	Essential	Demonstration
AVS-OP-VEH-011.10-v01	AVS-UN024-v01	Vehicle	Changing lanes (both left and right lane change).	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-011.11-v01	AVS-UN024-v01	Vehicle	Making right-of-way decisions when merging from a shuttle stop.	Essential	Demonstration
AVS-OP-VEH-011.12-v01	AVS-UN024-v01	Vehicle	Making right-of-way decisions at intersections.	Essential	Demonstration
AVS-OP-VEH-011.13-v01	AVS-UN024-v01	Vehicle	Making right-of-way decisions when interacting with vulnerable road users.	Essential	Demonstration
AVS-OP-VEH-011.14-v01	AVS-UN024-v01	Vehicle	Detecting and responding to encroaching oncoming vehicles.	Essential	Demonstration
AVS-OP-VEH-011.15-v01	AVS-UN024-v01	Vehicle	Detecting stopped vehicles in their path.	Essential	Demonstration
AVS-OP-VEH-011.16-v01	AVS-UN024-v01	Vehicle	Passing stopped vehicles when necessary and safe.	Essential	Demonstration
AVS-OP-VEH-011.17-v01	AVS-UN024-v01	Vehicle	Detecting and responding to static obstacles in their path.	Essential	Demonstration
AVS-OP-VEH-011.18-v01	AVS-UN024-v01	Vehicle	Detecting and responding to moving obstacles in their path (include construction equipment).	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-011.19-v01	AVS-UN024-v01	Vehicle	Detecting emergency vehicles, and when their sirens are on, and yielding appropriately or following directions of emergency officials.	Essential	Demonstration
AVS-OP-VEH-011.20-v01	AVS-UN024-v01	Vehicle	Detecting that they are being asked by law enforcement to move a specific way, and responding accordingly.	Essential	Demonstration
AVS-OP-VEH-011.21-v01	AVS-UN024-v01	Vehicle	Detecting and responding to vulnerable road users, such as pedestrians, cyclists, and scooters, in the vehicle's projected travel path, including at intersections and crosswalks.	Essential	Demonstration
AVS-OP-VEH-011.23-v01	AVS-UN024-v01	Vehicle	Providing a safe distance from vehicles, pedestrians, bicyclists, and scooters on the side of the road.	Essential	Demonstration
AVS-OP-VEH-011.24-v01	AVS-UN024-v01	Vehicle	Decreasing speed when there is uncertainty regarding which action to take.	Essential	Demonstration
AVS-OP-VEH-011.25-v01	AVS-UN024-v01	Vehicle	Detecting and responding to detours and other temporary changes in traffic patterns, such as people (including construction workers and police officers) directing traffic in unplanned or planned events. (An acceptable response includes informing the human Operator of the need to take manual control.)	Essential	Demonstration
AVS-OP-VEH-011.26-v01	AVS-UN024-v01	Vehicle	Operating in normal rain, fog, and light snow conditions not deemed a weather emergency.	Essential	Demonstration

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-OP-VEH-011.27-v01	AVS-UN024-v01	Vehicle	Operating in the roadway of the project area (With steep slopes and other conditions).	Essential	Demonstration
AVS-OP-VEH-011.28-v01	AVS-UN024-v01	Vehicle	Performing a low-speed merge.	Essential	Demonstration

Source: SFCTA

3.1.3 Performance Requirements

Table 5: Performance Requirements below identifies the AVS performance requirements for the project.

Table 5: Performance Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-PR-OPS-001-v01	NA	Operations	The Vendor shall provide service as detailed in the scope of work and agreed to with SFCTA.	Essential	Inspection
AVS-PR-OPS-002-v01	NA	Operations	Ridership shall be monitored by time-of-day and day-of-week, and operating hours may be adjusted to better accommodate demand, considering AVS capabilities.	Essential	

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-PR-OPS-003-v01	NA	Operations	The Vendor shall meet a minimum headway of as detailed in the scope of work and agreed to with SFCTA. As with operating hours, desired minimum headway may be modified during certain time periods depending on ridership but shall remain within the capabilities of the Vendor's originally proposed AVS fleet size. Stop departure times shall be scheduled to complement nearby Muni services.	Essential	Inspection

Source: SFCTA

3.1.4 Non-Functional Requirements

The non-functional requirements (NF) for the core system of interest specifies the characteristics of the overall operation of the system such as physical, availability, reliability, maintainability and storage and transport.

3.1.4.1 Physical Requirements

Table 6: Physical Requirements below identifies the AVS physical requirements for the project.

Table 6: Physical Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-PY-VEH-001-v01	NA	Vehicle	Each AVS shall have a minimum capacity of at least 4 passengers excluding the Operator.	Essential	Inspection
AVS-PY-VEH-002-v01	NA	Vehicle	While the AVS should have a minimum capacity of 4 passengers (excluding the Operator), higher (10+ person) capacity AVSs are preferred.	Desirable	Inspection
AVS-PY-VEH-003-v01	NA	Vehicle	The AVS shall also have space for passengers to store foldable wheelchairs and mobility devices, small amounts of luggage, such as grocery bags and strollers.	Essential	Inspection
AVS-PY-VEH-004-v01	NA	Vehicle	The Vendor shall agree to allow the AVSs to be wrapped or otherwise branded consistent with the intent of the deployment. Branding may include the Vendor's logo if desired alongside other graphics and sponsor brands. The Vendor shall provide limitations on placement of branding, to not occlude vital system functions, as part of its proposal. The final design will be coordinated with SFCTA.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-PY-VEH-005-v01	AVS-UN048-v01	Vehicle	The AVS should be all-electric or hybrid (electric with another fuel type).	Desirable	Inspection
AVS-PY-VEH-006-v01	NA	Vehicle	Each AVS shall have seatbelts for all seated passengers.	Essential	Inspection
AVS-PY-VEH-007-v01	NA	Vehicle	The AVS shall have non-slip covers for seats.	Essential	Inspection
AVS-PY-VEH-008-v01	NA	Vehicle	The AVS shall have handrails on the interior.	Essential	Inspection
AVS-PY-VEH-009-v01	AVS-UN049-v01	Vehicle	The AVS should have bike racks.	Desirable	Inspection
AVS-PY-VEH-010-v01	AVS-UN050-v01	Vehicle	The AVS should have free Wi-Fi (for passenger access).	Desirable	Inspection
AVS-PY-VEH-011-v01	NA	Vehicle	The AVS shall be model/manufacturer year 2020 or newer.	Essential	Inspection
AVS-PY-VEH-012-v01	NA	Vehicle	The AVS shall be free of any major dents, scratches, or other damage that may prevent the AVS from operating correctly or be cosmetically unappealing.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-PY-VEH-013-v01	NA	Vehicle	The Vendor shall include responses for the AVS's status to the USDOT National Highway Traffic Safety Administration (NHTSA) 12-point safety assessment, as well as whether the AVS has completed the assessment, whether the assessment has been submitted to NHTSA and, if not, whether there are any plans to do so.	Essential	Inspection
AVS-PY-VEH-014-v01	NA	Vehicle	The AVS shall comply with all applicable FMVSS or have approval to operate under an exemption to the FMVSS. If not compliant, describe how the items not in compliance are directly related to the full automation capability with no driver.	Essential	Test
AVS-PY-VEH-015-v01	AVS-UN025-v01	Vehicle	The AVS shall have climate control capabilities (heat and air conditioning).	Essential	Test
AVS-PY-VEH-016-v01	AVS-UN006-v01	Vehicle	The AVS shall be accessible to those with disabilities. (Onboard Operators will be on board each AVS during operations, and they may aid passengers beyond what the	Essential	Test

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
			AVS is independently capable of (such as securing a wheelchair or providing audible alerts).		
AVS-PY-VEH-017-v01	AVS-UN019-v01	Vehicle	The AVS shall be equipped with brake lights.	Essential	Test

Source: SFCTA

3.1.4.2 Availability and Reliability Requirements

Table 7: Availability and Reliability Requirements below identifies the AVS and AVS Management System availability and reliability requirements for the project.

Table 7: Availability and Reliability Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-AR-AOP-001-v01	NA	AVS Operations	The AVS shall be available for operations during the identified operational period for at least 98% of the pilot duration. (for example, if the total pilot is 90 days with 8 hours of operational period, the then the AVS shall be available for 98% x 90 x 8 = 705.6 hours).	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-AR-AOP-002-v01	AVS-UN047-v01	AVS Operations	The AVS should be available for 24/7 operations for at least 98% of the pilot duration.	Desirable	Inspection
AVS-AR-CMS-001-v01	AVS-UN013-v01	AVS Management System	The AVS Management system shall be available for operations during the AVS operational period for at least 99.999% of the time.	Essential	Inspection
AVS-AR-AOP-001-v01	AVS-UN013-v01	AVS On-Time Performance	The AVS shall arrive at a stop within 5 mins of arrival schedule.	Essential	Inspection
AVS-AR-AOP-002-v01	AVS-UN013-v01	AVS On-Time Performance	The AVS shall not depart from the stop more than 5 mins after scheduled departure time.	Essential	Inspection

Source: SFCTA

3.1.4.3 Maintainability Requirements

Table 8: Maintainability Requirements below identifies the AVS and AVS Management System maintainability requirements for the project.

Table 8: Maintainability Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-MR-AOP-001-v01	NA	AVS Operations	The AVS shall not be taken out of service for planned maintenance during operational period. (Planned maintenance shall be scheduled only during non- operational period).	Essential	Inspection
AVS-MR-AOP-002-v01	NA	AVS Operations	The AVS shall maintain electric charge for operations during the entire operational period (charging shall be done during off operational hours. Additional AVS may be used to provide service if AVS can't maintain charge through the operational period).	Essential	Inspection
AVS-MR-AOP-003-v01	NA	AVS Operations	The mean time to repair shall be less than 3 days for failure of any AVS component. (Vendor shall maintain the operational service by providing an alternate AVS during the repair period.)	Essential	Inspection
AVS-MR-AOP-004-v01	NA	AVS Operations	The vendor shall identify time and frequency of preventative maintenance as part of the Operations and Maintenance Plan.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-MR-AOP-005-v01	NA	AVS Operations	The vendor shall make available appropriately trained maintenance personnel (for performing charging, planned, and unplanned maintenance) as needed during the pilot duration.	Essential	Inspection

Source: SFCTA

3.1.4.4 Storage and Transport Requirements

Table 9: Storage and Transport Requirements below identifies the AVS storage and transport requirements for the project.

Table 9: Storage and Transport Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-ST-TPT-001-v01	AVS-UN026-v01	Transportation	The AVS shall have the ability to be towed or pushed by a support vehicle.	Essential	Inspection
AVS-ST-STG-001-v01	NA	Storage	The AVS shall be stored in a secured location during non-operational period.	Essential	Inspection

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-ST-STG-002-v01	NA	Storage	The Vendor shall maintain a maintenance and storage facility within the project area.	Essential	Inspection
AVS-ST-CHG-001-v01	NA	Charging	The Vendor shall install (or use an existing) charge station.	Essential	Inspection

Source: SFCTA

3.1.5 Data Requirements

Table 10: Data Requirements below identifies the data requirements for the project.

Table 10: Data Requirements

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-DT-DAT-001-v01	AVS-UN030-v01	Data	The Vendor shall agree to collect and store all raw data, including video, audio and sensor data. Video and audio shall be stored separately. Data should be made available to the SFMTA and SFCTA in the form and format requested (identified in these sub-requirements).. (Optionally, data	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
			that would be useful to potential passengers (such as real-time vehicle location information) will be shared via the APIs from the AVS Management System.)		
AVS-DT-DAT-001.1-v01	AVS-UN038-v01	Data	• Vehicle route and schedule in General Transit Feed Specification (GTFS) in real-time or near real-time.	Essential	Analyze
AVS-DT-DAT-001.2-v01	AVS-UN038-v01	Data	• Real-time vehicle location information in real-time or near real-time.	Essential	Analyze
AVS-DT-DAT-001.3-v01	AVS-UN038-v01	Data	• Trip updates and service alerts in real-time or near real-time.	Essential	Analyze
AVS-DT-DAT-001.4-v01	AVS-UN009-v01	Data	• Ridership (stop-level boardings and alightings), including time of rider boarding and alighting (daily).	Essential	Analyze
AVS-DT-DAT-001.5-v01	AVS-UN038-v01	Data	• Actual stop arrival and departure times (daily).	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-DT-DAT-001.6-v01	AVS-UN038-v01	Data	• Vehicles miles traveled (daily).	Essential	Analyze
AVS-DT-DAT-001.7-v01	AVS-UN038-v01	Data	• Vehicle hours traveled (hours the vehicle is in service) (daily).	Essential	Analyze
AVS-DT-DAT-001.8-v01	AVS-UN038-v01	Data	• Number of route-trips served (daily).	Essential	Analyze
AVS-DT-DAT-001.9-v01	AVS-UN038-v01	Data	• Duration of each trip (daily).	Essential	Analyze
AVS-DT-DAT-001.10-v01	AVS-UN038-v01		• Grams of CO_2 per passenger mile (if applicable) (weekly).	Essential	Analyze
AVS-DT-DAT-001.11-v01	AVS-UN038-v01	Data	• Battery capacity/usage (such that it can be associated with weather, temperature, vehicle load, etc.) (weekly).	Essential	Analyze
AVS-DT-DAT-001.12-v01	AVS-UN038-v01	Data	• Average vehicle speeds along each segment of the route (weekly).	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-DT-DAT-001.13-v01	AVS-UN038-v01	Data	• Count and duration of wheelchair ramp or lift deployments (weekly).	Essential	Analyze
AVS-DT-DAT-001.14-v01	AVS-UN038-v01	Data	• Sensor and other telemetry data (weekly).	Essential	Analyze
AVS-DT-DAT-001.15-v01	AVS-UN038-v01	Data	• Navigation variances (weekly).	Essential	Analyze
AVS-DT-DAT-001.16-v01	AVS-UN038-v01	Data	• Mechanical data (vehicle condition) (weekly).	Essential	Analyze
AVS-DT-DAT-001.17-v01	AVS-UN038-v01	Data	• Disengagements by the operator or the system with the disengagement timestamps, locations, and causes (weekly).	Essential	Analyze
AVS-DT-DAT-001.18-v01	AVS-UN038-v01	Data	• Any other safety incidents events (hard stops, near misses, evasive maneuvers, unruly passenger behavior, etc.) (weekly).	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-DT-DAT-001.19-v01	AVS-UN038-v01	Data	• Percent of time during operating hours the system is shut down (cause)(weekly).	Essential	Analyze
AVS-DT-DAT-001.20-v01	AVS-UN038-v01	Data	• Number of security breach attempts, immediate reporting (weekly aggregate).	Essential	Analyze
AVS-DT-DAT-001.21-v01	AVS-UN038-v01	Data	• Number of successful security breaches, immediate reporting (weekly aggregate).	Essential	Analyze
AVS-DT-DAT-001.22-v01	AVS-UN038-v01	Data	• Conditions driven in (weather, congestion, etc.) (weekly).	Essential	Analyze
AVS-DT-DAT-001.123-v01	AVS-UN038-v01	Data	• Incident reports (including any collisions or crimes) within 24 hours or sooner, following an incident. All data (video, audio, sensors, etc.) 5 minutes before and after each incident should be included.	Essential	Analyze
AVS-DT-DAT-001.24-v01	AVS-UN038-v01	Data	• Passenger Behavior reports (including any situations when an external entity is called upon for assistance and is not deemed an imminent	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
			passenger safety concern) within one week following an incident. All data (video, audio, sensors, etc.) 5 minutes before and after each incident should be included.		
AVS-DT-DAT-001.25-v01	AVS-UN038-v01	Data	• User and non-user surveys (before and after the pilot).	Essential	Analyze
AVS-DT-DAT-001.26-v01	AVS-UN038-v01	Data	• Number of times people with disabilities were able to hail, board, secure themselves, or alight with and without concierge assistance (weekly), and number of times people with disabilities were not able to hail, board, secure themselves, or alight with and without concierge assistance (weekly).	Essential	Analyze
AVS-CO-DAT-001.27-v01	AVS-UN038-v01	Data	• Number of bicycles on board the AVS (weekly) and number of bicycles that were not able to board AVs due to space constraints.	Essential	Analyze

ReqID	User Need ID	Functional Group	Description	Priority	Verification Method
AVS-CO-DAT-001.28-v01	AVS-UN038-v01	Data	• Annualized operating expense per service mile (end of pilot).	Essential	Analyze
AVS-CO-DAT-001.29-v01	AVS-UN038-v01	Data	• If a Connected Vehicle On-Board Unit is used, a record of operational data exchanged (includes SPaT and MAP messages the vehicle receives, BSM it sends, etc.) (weekly).	Desirable	Analyze

3.1.6 ADA Compliance

The Vendor shall identify its ability to comply with all applicable requirements of the Americans with Disabilities Act of 1990 (ADA), 42 U.S.C. 12101 et seq. and 49 U.S.C. 322; Section 504 of the Rehabilitation Act of 1973, as amended, 29 U.S.C. 794; Section 16 of the Federal Transit Act, as amended, 49 U.S.C. app. 1612; and the following regulations and any amendments thereto:

- USDOT regulations, "Transportation Services for Individuals with Disabilities (ADA)," 49 CFR. Part 37;
- USDOT regulations, "Nondiscrimination on the Basis of Handicap in Programs and Activities Receiving or Benefiting from Federal Financial Assistance," 49 CFR. Part 27;
- US. DOT regulations, "Americans With Disabilities (ADA) Accessibility Specifications for Transportation Vehicles," 49 CFR. Part 38;
- Department of Justice (DOJ) regulations, "Nondiscrimination on the Basis of Disability in State and Local Government Services," 28 CFR. Part 35;
- DOJ regulations, "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities," 28 CFR. Part 36;
- General Services Administration regulations, "Construction and Alteration of Public Buildings," "Accommodations for the Physically Handicapped," 41 CFR. Part 101-19;
- Equal Employment Opportunity Commission (EEOC) "Regulations to Implement the Equal Employment Provisions of the Americans with Disabilities Act," 29 CFR. Part 1630;
- Federal Communications Commission regulations, "Telecommunications Relay Services and Related Customer Premises Equipment for the Hearing and Speech Disabled," 47 CFR. Part 64, Subpart F; and FTA regulations, "Transportation for Elderly and Handicapped Persons," 49 CFR Part 609.

4 Engineering Principles

This section describes engineering principles that guide composition of the TIMMA Autonomous Vehicle Shuttle Pilot Project.

4.1 Methods of Verification

The software and hardware components that make up the TIMMA Autonomous Vehicle Shuttle Pilot Project will be individually verified, then integrated to produce top-level assemblies and microservices. These assemblies will also be individually verified before being integrated with others to produce larger, evolving assemblies until the complete system has been integrated and verified.

The requirements also maintain a verification method, which details the plan for verifying the requirement based on its stated definition. One of the verification methods listed in **Table 11: Methods of Verification** is assigned for each requirement. Using the requirements defined in the previous section,

Table 11: Methods of Verification

Type	Description
Inspection	Verification through a visual, auditory, olfactory, or tactile comparison
Demonstration	Verification that exercises the system software or hardware as it is designed to be used, without external influence, to verify the results are specified by the requirement
Test	Verification using controlled and predefined inputs and other external elements (e.g. data, triggers, etc.) that influence or induce the system to produce the output specified by the requirement
Analyze	Verification through indirect and logical conclusion using mathematical analysis, models, calculations, testing equipment and derived outputs based on validated data sets

Source: SFCTA

THE LOOP FINAL EVALUATION REPORT
APPENDIX G

Monthly Operations Reports (September, October, November)

Treasure Island AV Shuttle Pilot Project

To:	Aliza Paz (SFCTA), Drew Cooper (SFCTA)
From:	Esteban Martinez (HNTB), Rich Shinn (HNTB)
Date:	12/15/2023
Subject:	Monthly Summary Report – September 2023

The following attachments summarize key performance and evaluation metrics for the AV Shuttle Pilot Operations in the month of September. Below is a summary of the information contained in the attachments. It is worth noting that, prior to 9/10, all shuttles were out of service due to prior incidents. After undergoing a formal test period, shuttle P32 began service on 9/10. Similarly, shuttle P84 began service on 9/27.

Chart 1 – Ridership (total boarded passengers):

- A total of 217 passengers boarded shuttles during the month of September. As shown, total ridership grew as the weeks progressed, reaching nearly 100 riders in the last week of the month.

Chart 2 – Average Headways (average time interval between shuttles arriving at stop locations):

- During the first three weeks of the month, average headways were above 30 minutes. With the introduction of shuttle P84 in the last week of the month, two shuttles were operating on the route and average headways were at or below 27 minutes. The goal for the project is to achieve 27-minute headways.

Chart 3 – Average Dwell Time (average time shuttles are stopped at stop locations to pick-up/drop-off passengers):

- Average dwell times were typically above 2 minutes. It should be noted that dwell times are influenced by instances in which operators require breaks and/or midday shift swaps, or other external factors, such as when GNSS connectivity loss occurs. With the introduction of P84 in the last week of the month, shift swaps were no longer required and average dwell times decreased to be just over 2 minutes, on average.

Chart 4 – Average Shuttle Speeds (average shuttle speeds between stop locations):

- As shown, shuttles were typically traveling around 5 MPH between stop locations. While the shuttles are permitted to travel at higher speeds, this average speed considers the need for shuttles to adhere to stop signs and other stopping/slowing instances along the travel path.

Chart 5 – Disengagements by Cause (instances in which shuttle operators are required to manually operate the shuttle):

- There was a total of 52 shuttle disengagements in September. Most disengagements were attributed to activity on the island by other road users. During the month of September, shuttle operators noted an uptick in construction and vehicle activity along the corridor.

Chart 6 – Incidents by Cause (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event):

- No incidents were reported in September.

Chart 7 – Ridership by Shuttle (total boarded passengers, recorded by shuttle):

- With the introduction of shuttle P84, ridership was shared between both vehicles in the last week of the month. Week over week ridership increased by nearly two-fold for the last week of September in comparison to the other prior weeks of the month.

Chart 8 – Disengagements by Shuttle (instances in which shuttle operators are required to manually operate the shuttle, recorded by shuttle):

- Most disengagements were observed on shuttle P32. However, given shuttle P84 was not operational until the last week of the month, this was expected.

Chart 9 – Incidents by Shuttle (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event, recorded by shuttle):

- No incidents were reported in September.

Chart 10 – Service Miles by Shuttle (total miles traveled while providing service to passengers, recorded by shuttle):

- A total of 633 service miles were recorded in September. Shuttle P32 recorded the bulk of the service miles, as expected.

Chart 11 – Service Hours by Shuttle (total hours of service provided to passengers, recorded by shuttle):

- A total of 205 service hours were recorded in September. Shuttle P32 recorded the bulk of the service hours, as expected.

Table 1 – Survey Response Tracking (summary of survey respondents monthly and since the start of the pilot)

- There were 20 survey respondents in September. Of these, 40% identified as riders, 35% identified as non-riders, and 25% did not identify.

Table 2– Service Uptime (the ability for the vendor to provide on-going passenger service, based an expected level of service 9AM-6PM daily)

- In September, the vendor was only able to provide passenger service 68% of the time (based on expected time traveled) and completed only 66% of their runs (based on expected loops around the island). This was largely attributed to the shuttles being out of service the first week, and the need for shift swaps in the second and third week when only one shuttle was operational.

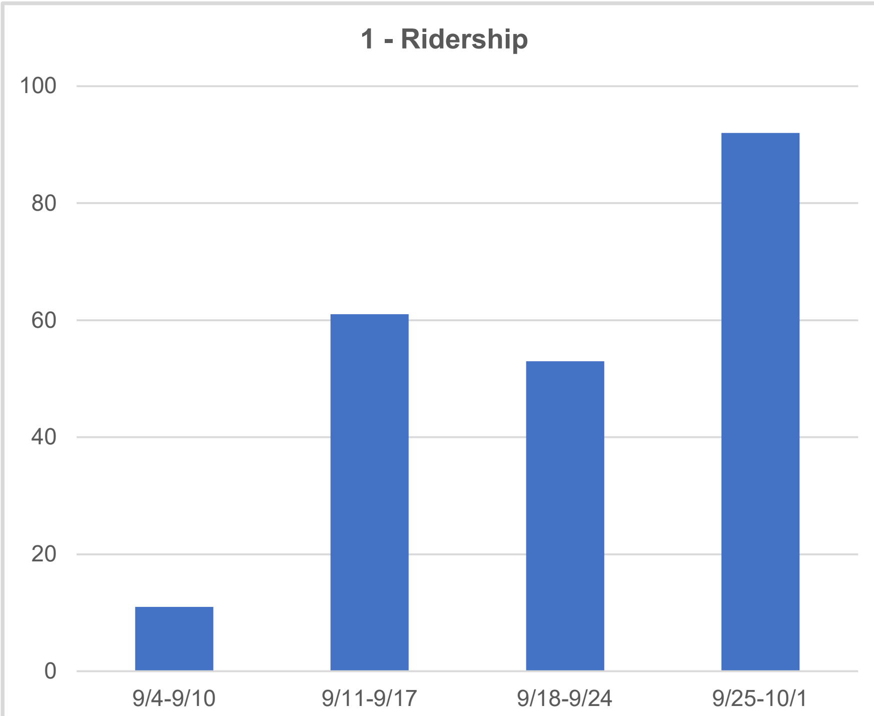
Table 3 — Additional Service Metrics

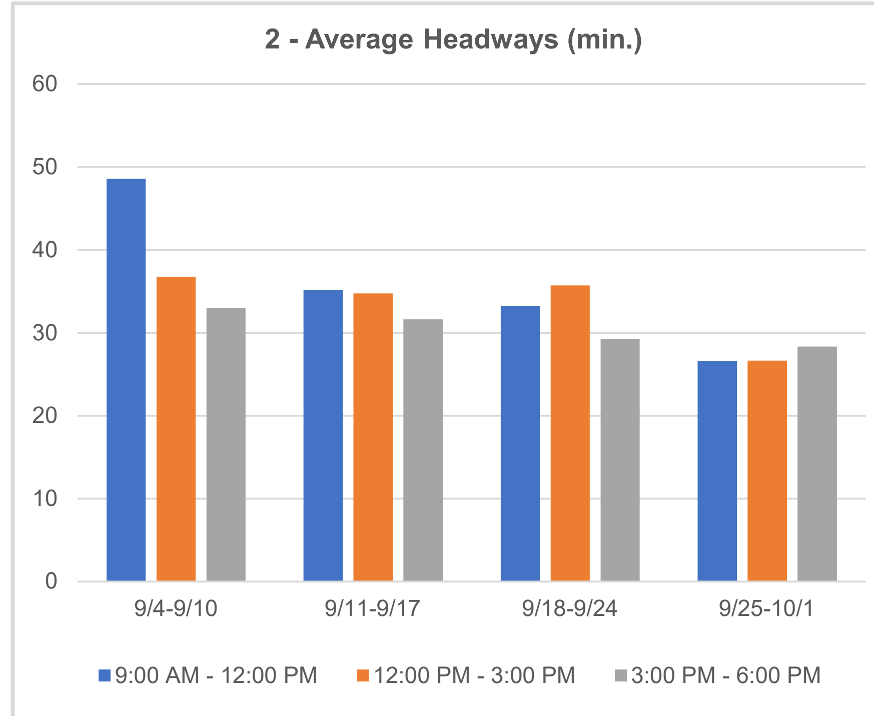
- There was only 1 reported ramp deployment and wheelchair securement in the month.
- Average Ending Battery % (the average battery life recorded at the end of an attendant's shift) showed there were no issues with battery usage or charging for any week or vehicle in September. For most of the month, P32 was the only vehicle operating and it averaged a battery usage of approximately 15% per shift.
- There were no incidents, therefore incidents per mile were recorded as zero.
- While there were less shuttle disengagements per mile in the third week of the month, this appears to be attributed to a lower presence of other road users.

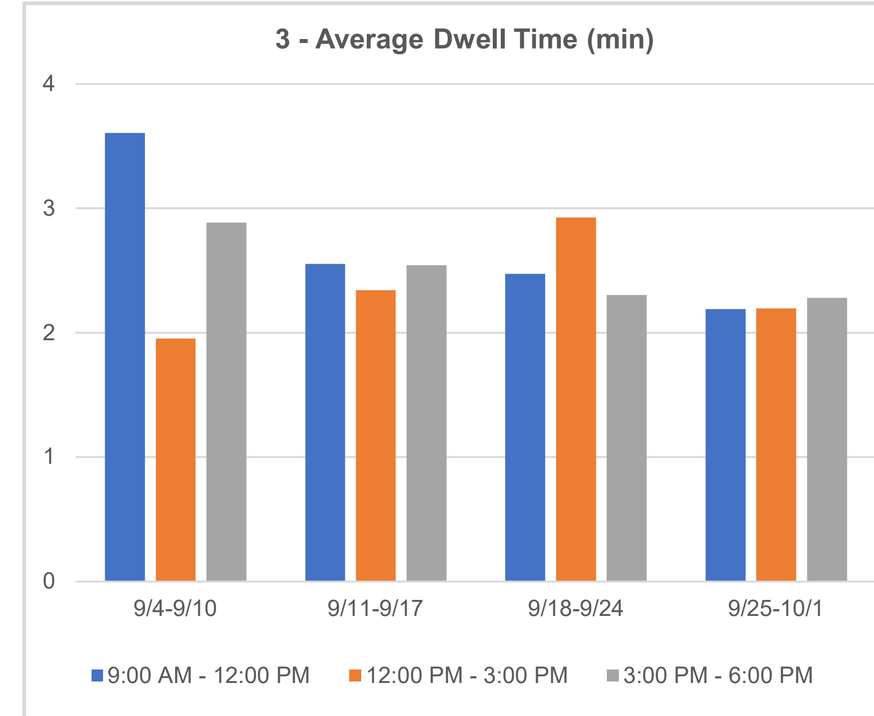
Map 1 — Reported Signal Losses

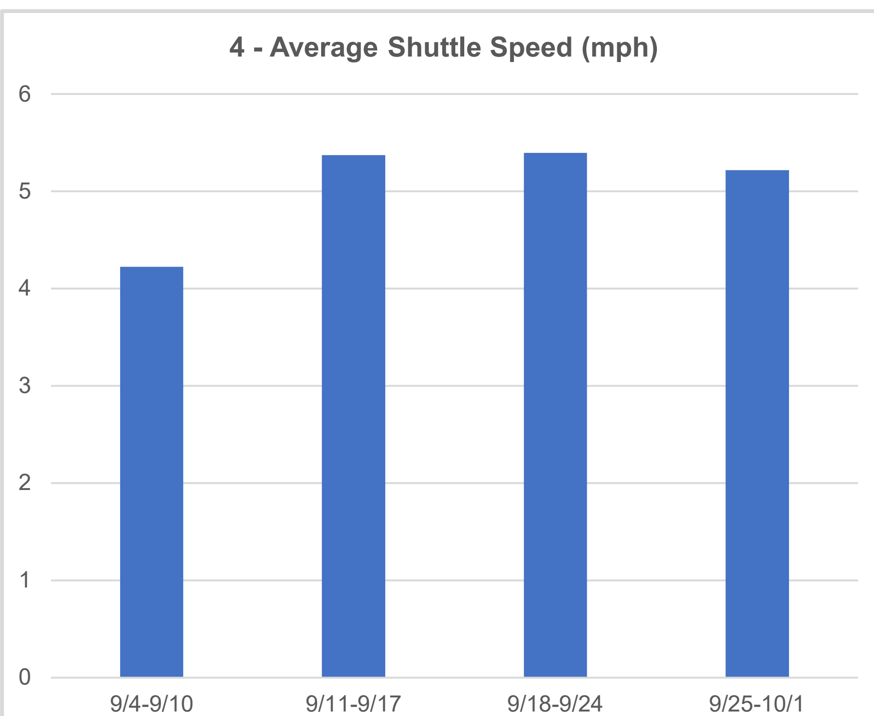
- There were only 3 reported signal losses in the month of September. Currently, they do not appear correlated to a particular location. This will be further evaluated in future months.

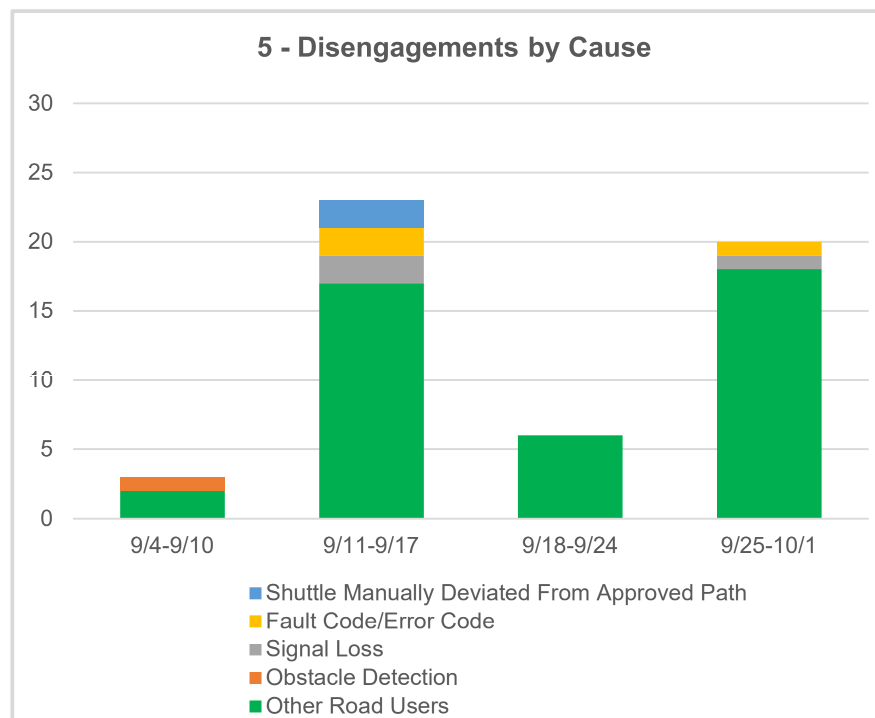
Monthly Summary Dashboard (September)

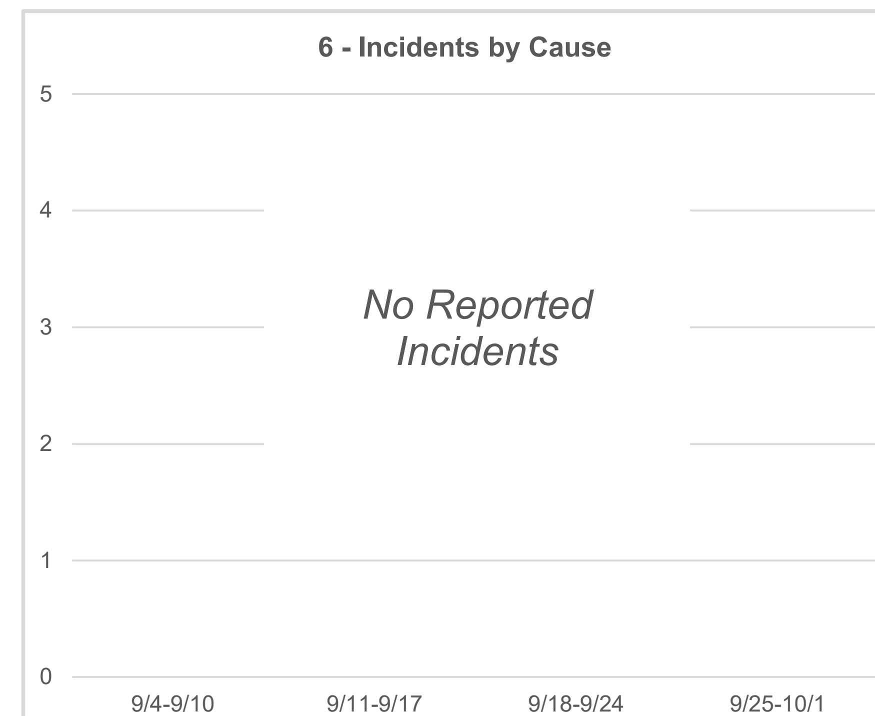








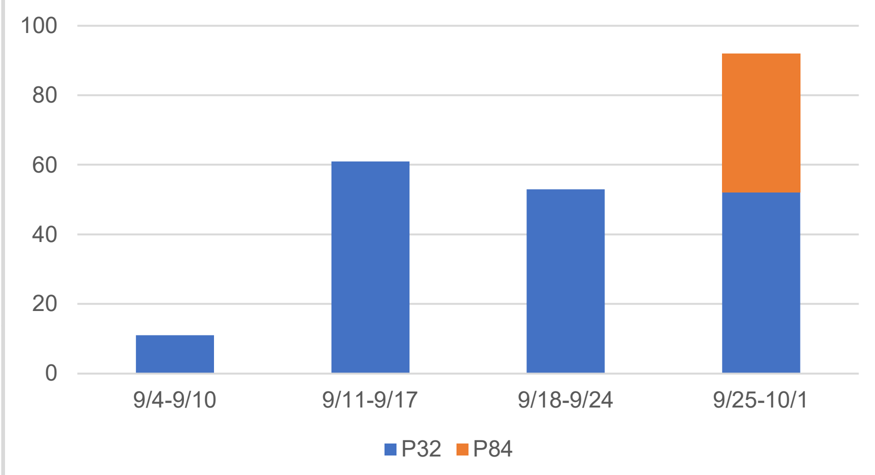




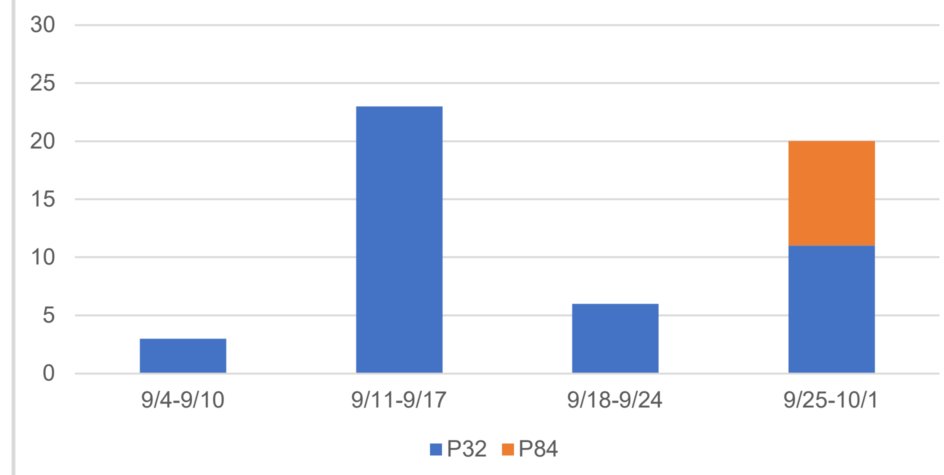
Note: Week 9/4 - 9/10 only includes data for 9/10. P32 shuttle began service on 9/10.

Summary of Incidents Involving First Responders: There were no reported incidents in the month of September.

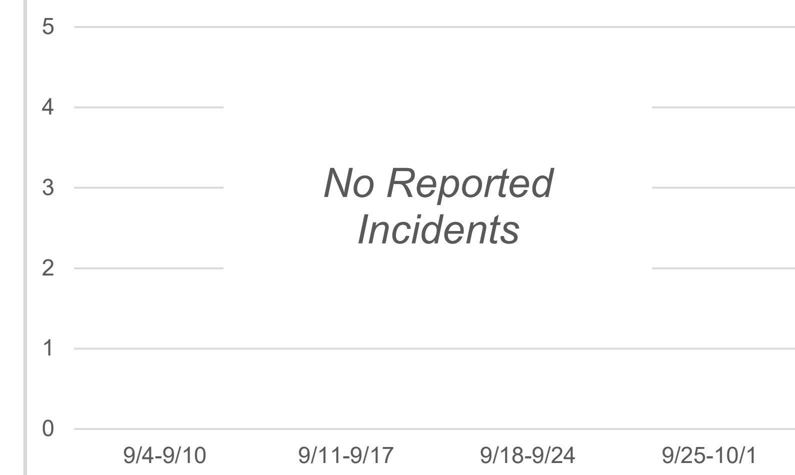
Monthly Summary Dashboard (September)



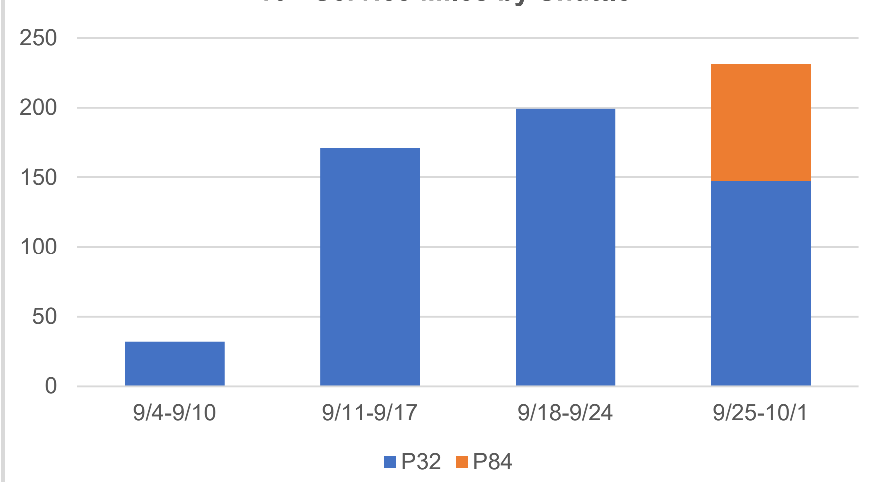
7 - Ridership by Shuttle



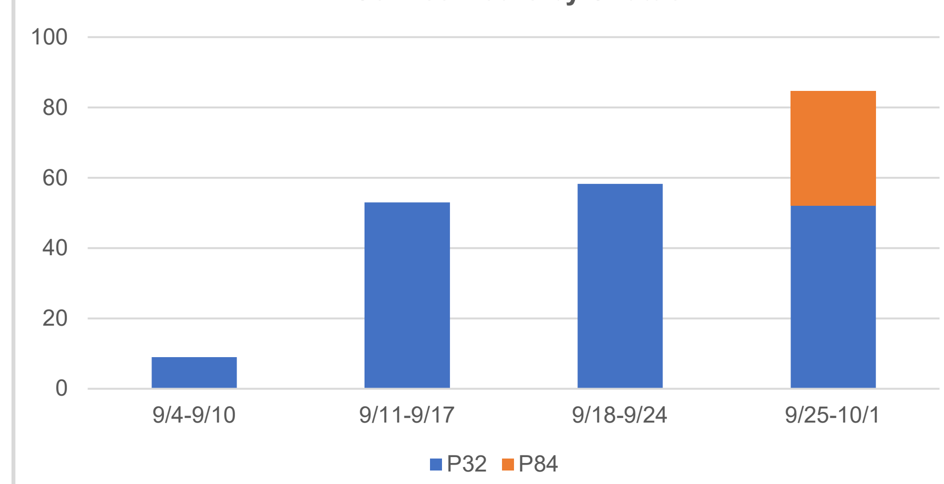
8 - Disengagements by Shuttle



9 - Incidents by Shuttle



10 - Service Miles by Shuttle



11 - Service Hours by Shuttle

Map 1 - Reported Signal Losses

Table 1 - Survey Response Tracking

Monthly Reponses	Monthly % (Rider/Non Rider/NA)	Total Responses	Total % (Rider/Non Rider/NA)
20	40% / 35% / 25%	57	33% / 39% / 28%

Table 2 - Service Uptime

% Time Traveled	% Runs Completed
68%	66%
Exception for Hours *	**Exception for Runs ***
7	15.5

Table 3 - Additional Metrics

Week	Ramp Deployments	Wheel Chair Securements	Avg. Ending Battery %	Incidents / Mile	Disengage. / Mile
9/4-9/10	0	0	60	0	0.187
9/11-9/17	0	0	73	0	0.158
9/18-9/24	0	0	69	0	0.040
9/25-10/1	1	1	78	0	0.100
Shuttle					
P32	0	0	72	0	0.100
P84	1	1	85	0	0.108

Note: Week 9/4 - 9/10 only includes data for 9/10. P32 shuttle began service on 9/10.

* Exceptions Given for Service Uptime: On 9/16, there was a planned service distruption due to local music festival which accounted for 7 hours, and an estimated 15.5 runs.

Treasure Island AV Shuttle Pilot Project

To:	Aliza Paz (SFCTA), Drew Cooper (SFCTA)
From:	Esteban Martinez (HNTB), Rich Shinn (HNTB)
Date:	1/15/2024
Subject:	Monthly Summary Report – October 2023

The following attachments summarize key performance and evaluation metrics for the AV Shuttle Pilot Operations in the month of October. Below is a summary of the information contained in the attachments. It is worth noting that there were multiple shuttles being out of service for some periods of time due to testing and repairs throughout the month:

- P66 was not in service until the end of October.
- 10/13 - P32 was taken out of service for repairs.
- 10/23 - P32 was put back into service.
- 10/24 - P84 was taken out of service due to LIDAR issues from local rainstorm and was not in service the remainder of the month.
- 10/26 - P32 was taken out of service for repairs midday.
- 10/27 - P66 was put back into service.
- 10/28 - P32 was put back into service.

Chart 1 – Ridership (total boarded passengers):

- A total of 299 passengers boarded shuttles during the month of October. This is a near 38% growth in ridership month over month. As shown, total ridership ranges between 80-100 passengers throughout the weeks, except for the final week due to shuttles being pulled out of service for repairs.

Chart 2 – Average Headways (average time interval between shuttles arriving at stop locations):

- The goal for the project is to achieve 27-minute headways. Average headways remained consistent for the first two weeks with two shuttles in operation, staying at or below 27 minutes during the first week and at or below 29 minutes in the second week. From week 3 onwards, average headways started to increase as shuttles were taken out of service for repairs. To date, all 3 shuttles have not been operational within the same time frame.

Chart 3 – Average Dwell Time (average time shuttles are stopped at stop locations to pick-up/drop-off passengers):

- In the first two weeks, average dwell times were below 2.5 minutes. With multiple shuttles running simultaneously, shift swaps were not required and average dwell times remained low. However, due to some shuttles requiring repairs, the average dwell time increased during the last two weeks of the month where only one shuttle was operating.

Chart 4 – Average Shuttle Speeds (average shuttle speeds between stop locations):

- As shown, shuttles were typically traveling below 5 MPH between stop locations. While the shuttles are permitted to travel at higher speeds, this average speed considers the need for shuttles to adhere to stop signs and other stopping/slowing instances along the travel path.

Chart 5 – Disengagements by Cause (instances in which shuttle operators are required to manually operate the shuttle):

- There was a total of 102 shuttle disengagements in October, nearly twice the amount of instances month over month. Most disengagements were attributed to activity on the island by "Other Road Users". There were also more signal loss events than the prior month, which is discussed further below in the "Map 1" notes.

Chart 6 – Incidents by Cause (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event):

- No incidents were reported in October.

Chart 7 – Ridership by Shuttle (total boarded passengers, recorded by shuttle):

- With the introduction of multiple shuttles, ridership was shared among the vehicles throughout the month except for week 3 when only P84 was operating.

Chart 8 – Disengagements by Shuttle (instances in which shuttle operators are required to manually operate the shuttle, recorded by shuttle):

- Most disengagements were observed on shuttle P84. The drop in instances for week 3 can be the result of only P84 operating due to P32 undergoing repairs. In week 4, P66 and P32 attributed for most of the disengagements due to P84 being taken out of service.

Chart 9 – Incidents by Shuttle (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event, recorded by shuttle):

- No incidents were reported in October.

Chart 10 – Service Miles by Shuttle (total miles traveled while providing service to passengers, recorded by shuttle):

- A total of 809 service miles were recorded in October which is a 28% increase month over month as multiple vehicles were running simultaneously throughout the month. Shuttle P84 recorded the bulk of the service miles since P84 was operating most days of the month.

Chart 11 – Service Hours by Shuttle (total hours of service provided to passengers, recorded by shuttle):

- A total of 286 service hours were recorded in October. Shuttle P84 recorded most of the service hours, as expected.

Table 1 – Survey Response Tracking (summary of survey respondents monthly and since the start of the pilot)

- There were 13 survey respondents in October. Of these, 62% identified as riders and 38% identified as non-riders.

Table 2– Service Uptime (the ability for the vendor to provide on-going passenger service, based an expected level of service 9AM-6PM daily)

- In October, the vendor was only able to provide passenger service 85% of the time (based on expected time traveled) and completed 88% of their runs (based on expected loops around the island). This was largely attributed to longer periods of downtime because of the shuttles being out of service throughout the month.

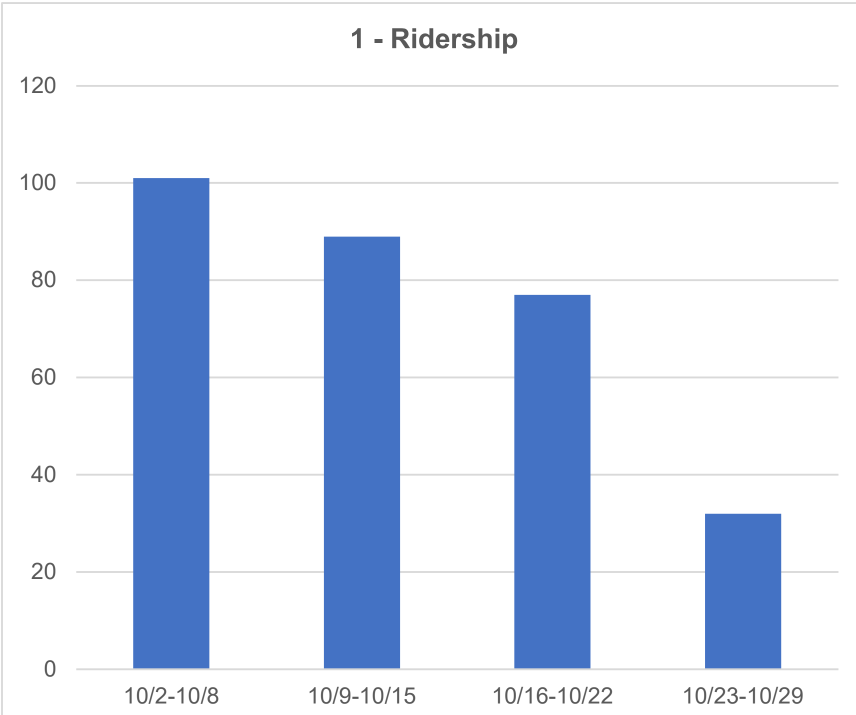
Table 3 – Additional Service Metrics

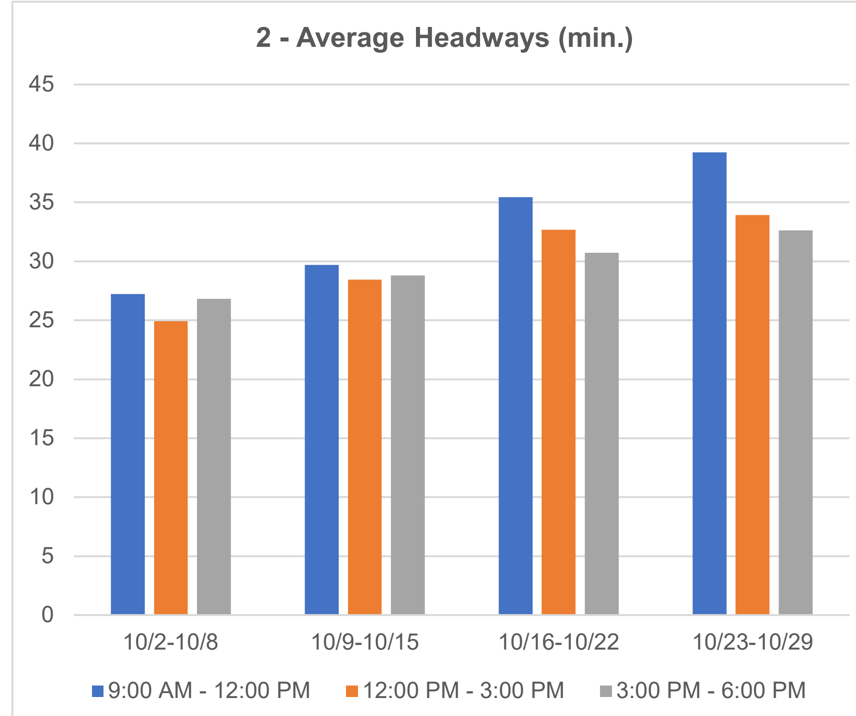
- There were 5 reported ramp deployments and 3 reported wheelchair securements for the month.
- Average Ending Battery % (the average battery life recorded at the end of an attendant's shift) showed there were no issues with battery usage or charging for any week or vehicle in October.
- There were no incidents, therefore incidents per mile were recorded as zero.
- In additional to having the highest number of disengagements in the month, shuttle P84 also appears to have a higher number of disengagements per mile. While not conclusive, this may point to a vehicle specific issue. As additional data becomes available, this will continue to be monitored.

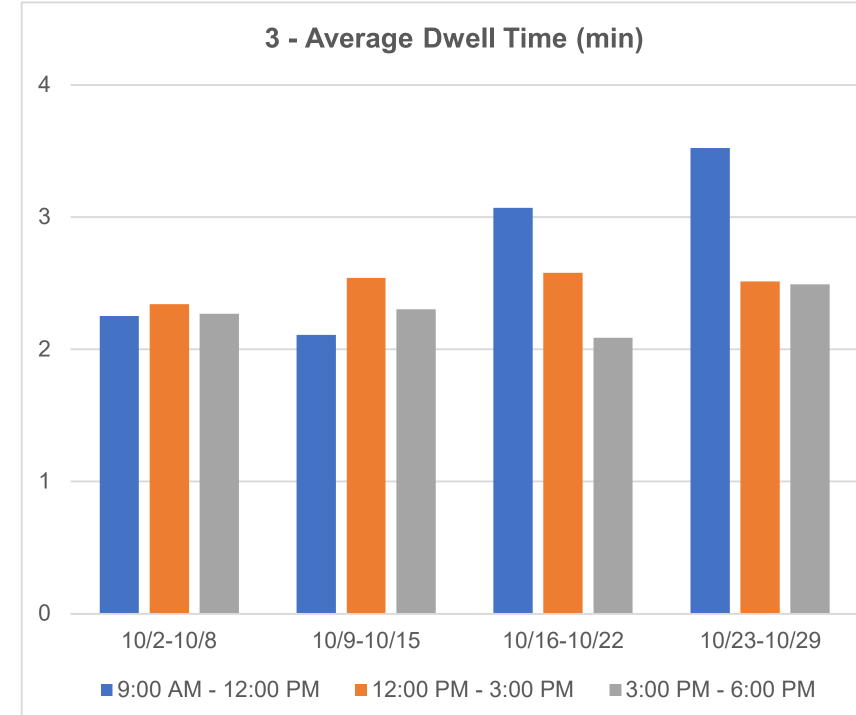
Map 1 – Reported Signal Losses

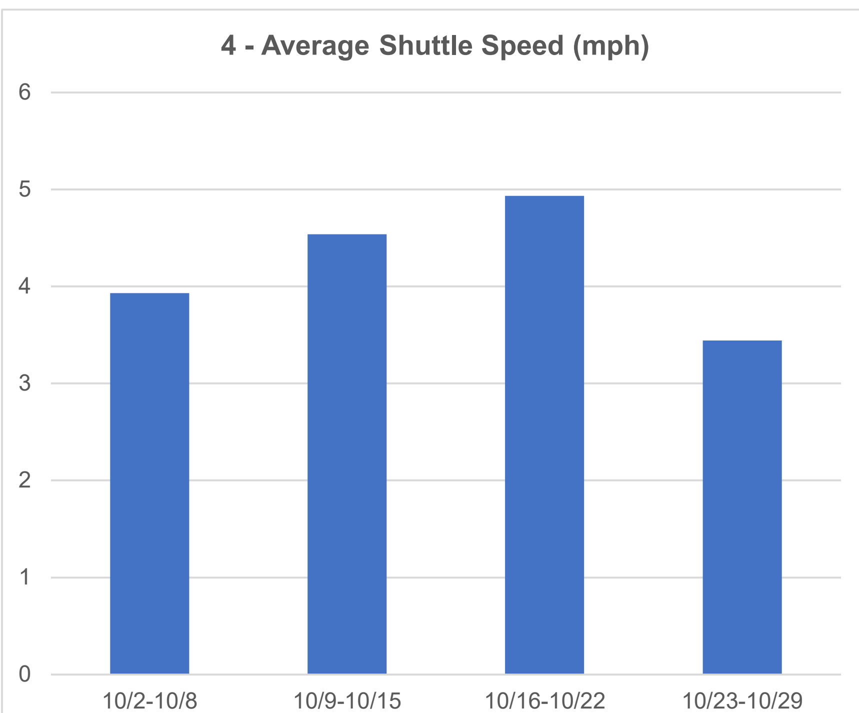
- There were 14 reported signal losses in the month of October. There appears to be a pattern of signal loss instances occurring near the Ship Shape Community Center. This will continue to be monitored in future reporting.

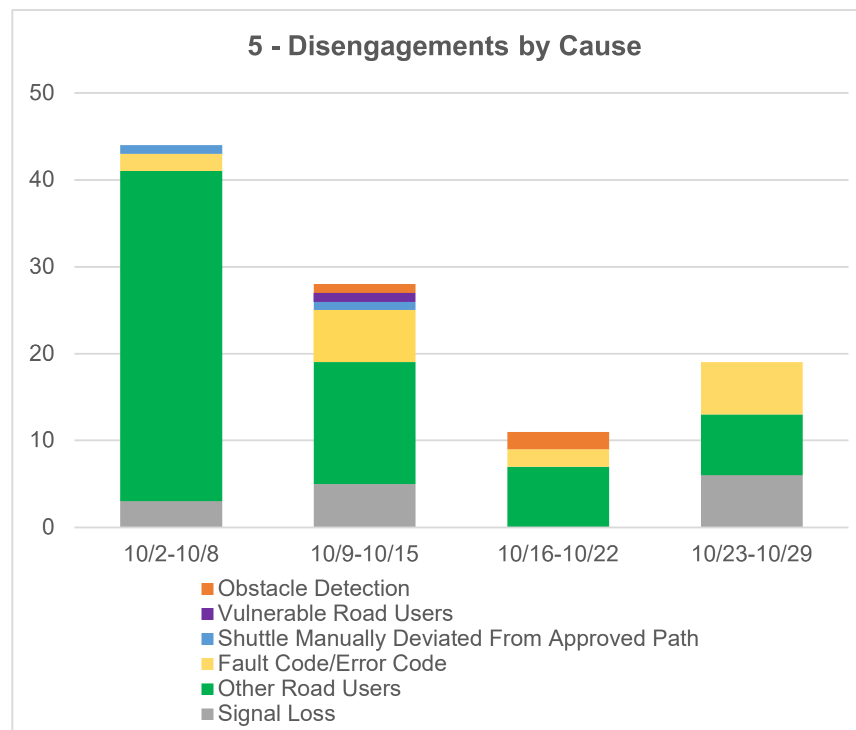
Monthly Summary Dashboard (October)

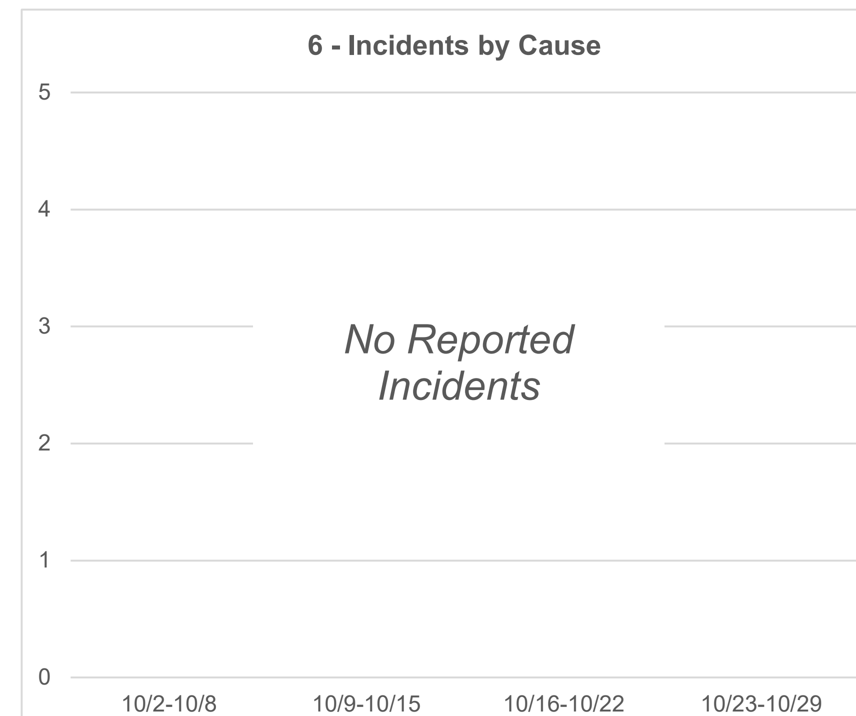






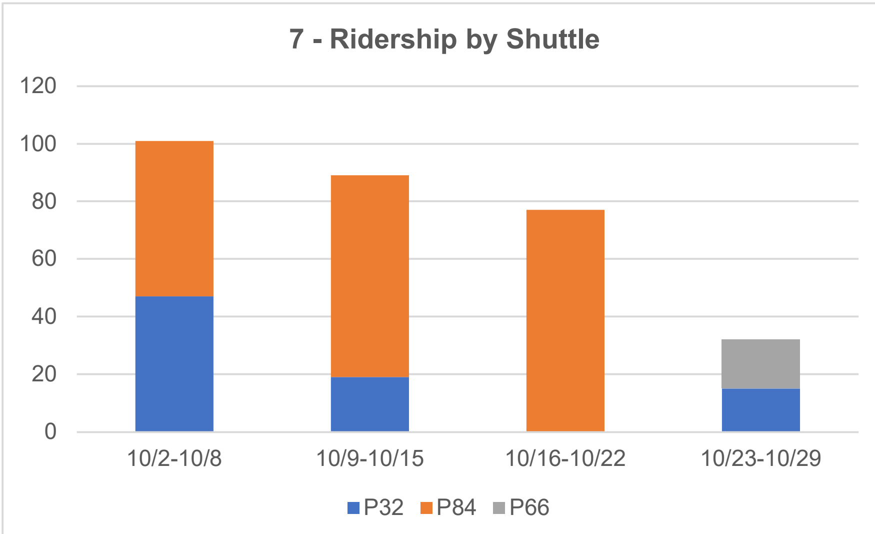


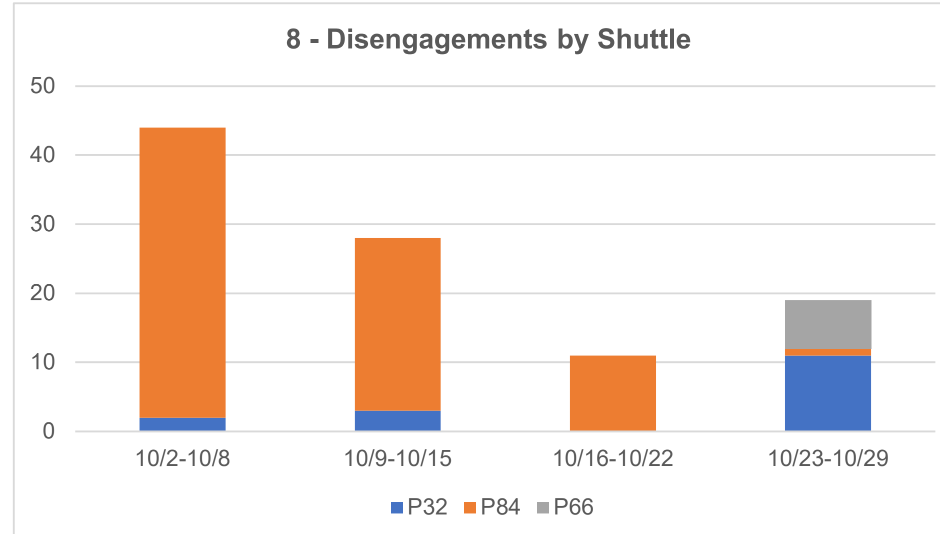


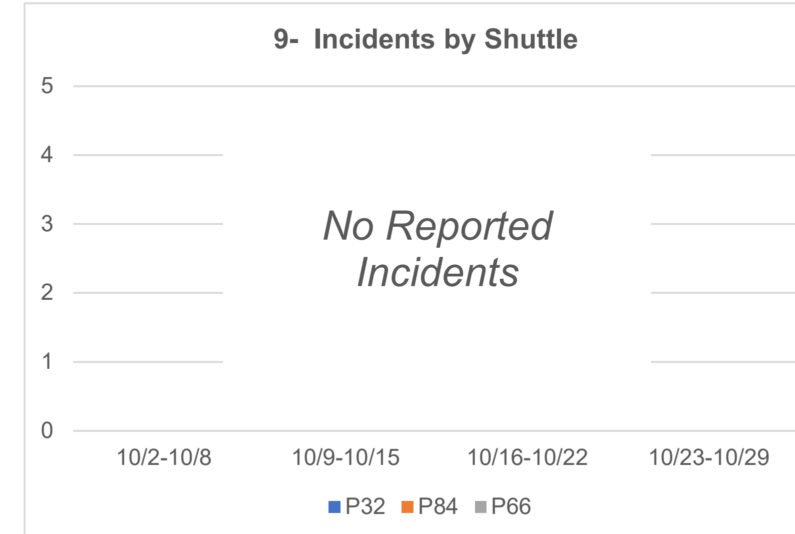


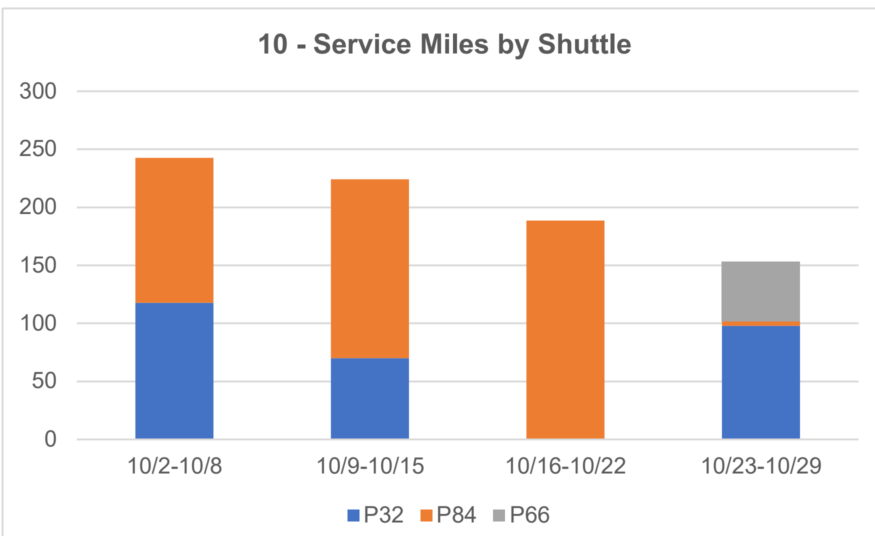
Summary of Incidents Involving First Responders: N/A

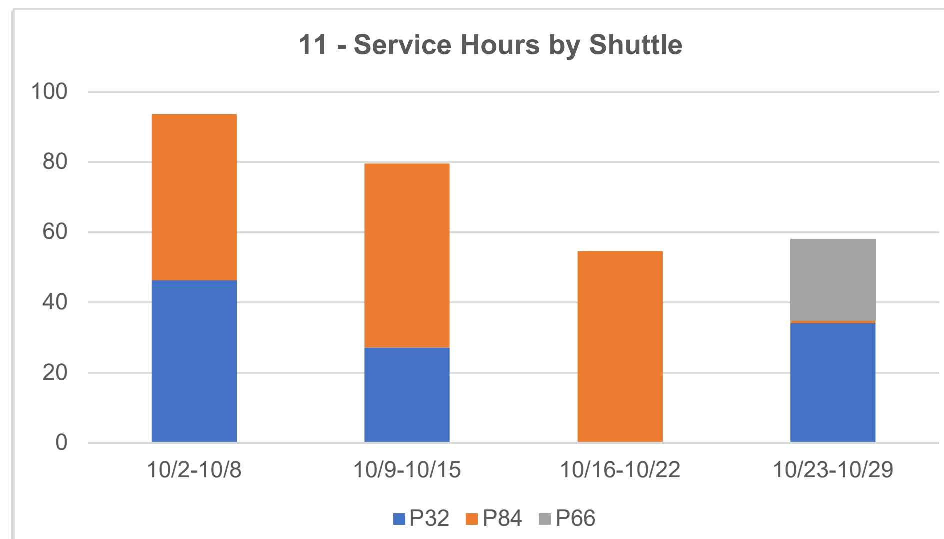
Monthly Summary Dashboard (October)











Map 1 - Reported Signal Losses

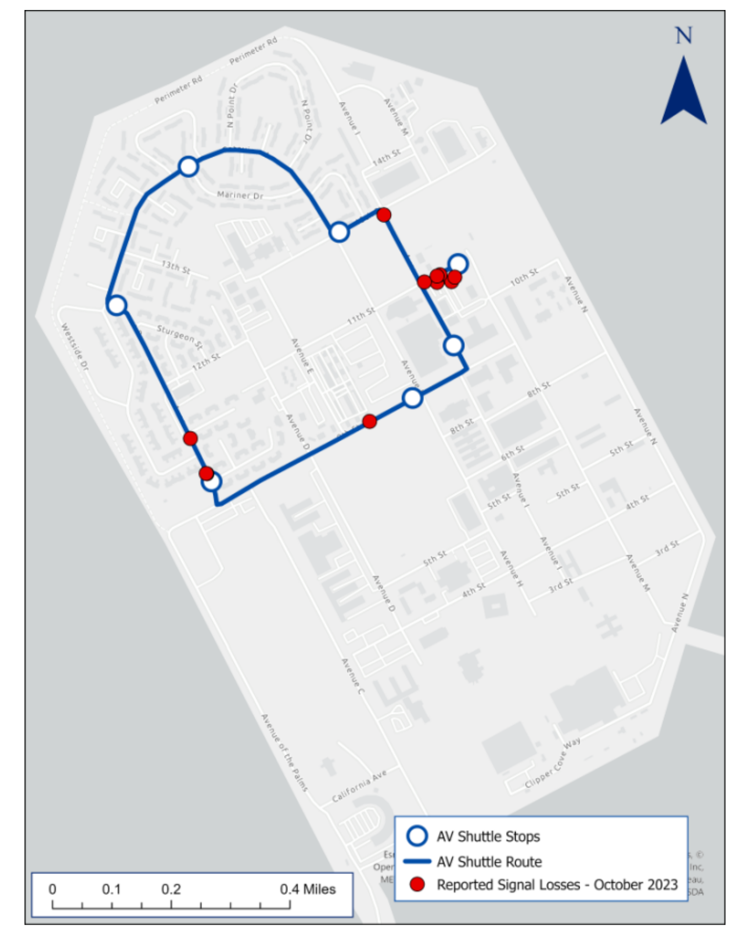


Table 1 - Survey Response Tracking			
Monthly Reponses	Monthly % (Rider/Non Rider/NA)	Total Responses	Total % (Rider/Non Rider/NA)
13	62% / 38% / 0%	70	39% / 39% / 23%

Table 2 - Service Uptime	
% Time Traveled	% Runs Completed
85%	88%
Exception for Hours	Exception for Runs
0	0

Table 3 - Additional Metrics					
Week	Ramp Deployments	Wheel Chair Securements	Avg. Ending Battery %	Incidents / Mile	Disengage. / Mile
10/2-10/8	2	2	66	0	0.181
10/9-10/15	2	0	70	0	0.125
10/16-10/22	0	0	67	0	0.058
10/23-10/29	1	1	78	0	0.124
Shuttle					
P32	2	2	77	0	0.056
P84	2	0	65	0	0.168
P66	1	1	80	0	0.136

Treasure Island AV Shuttle Pilot Project

To:	Aliza Paz (SFCTA), Drew Cooper (SFCTA)
From:	Esteban Martinez (HNTB), Rich Shinn (HNTB)
Date:	1/15/2024
Subject:	Monthly Summary Report – November 2023

The following attachments summarize key performance and evaluation metrics for the AV Shuttle Pilot Operations in the month of November. Below is a summary of the information contained in the attachments. It is worth noting that, on 11/21, shuttle P84 was put back into service. From then on, all 3 shuttles were operating on the route.

Chart 1 – Ridership (total boarded passengers):

- A total of 456 passengers boarded shuttles in November. As shown, total ridership averaged around 90 passengers throughout the weeks, except for week 3. This is likely attributable to the road work on Treasure Island that was being done during this timeframe.

Chart 2 – Average Headways (average time interval between shuttles arriving at stop locations):

- The goal for the project is to achieve 27-minute headways. Average headways were higher during the first two weeks, fluctuating between 32 minutes and 24 minutes depending on the time of day. From then onwards, the average headways stayed below the 27-minute target once multiple shuttles were in service.

Chart 3 – Average Dwell Time (average time shuttles are stopped at stop locations to pick-up/drop-off passengers):

- In the first three weeks, average dwell times were at or below 2.5 minutes. With multiple shuttles running simultaneously, shift swaps were not required and average dwell times remained low. As all 3 shuttles operated from week 4 onwards, dwell times decreased and stayed below the 2-minute mark.

Chart 4 – Average Shuttle Speeds (average shuttle speeds between stop locations):

- As shown, shuttles were typically traveling between 4.5-5 MPH between stop locations. While the shuttles are permitted to travel at higher speeds, this average speed considers the need for shuttles to adhere to stop signs and other stopping/slowing instances along the travel path.

Chart 5 – Disengagements by Cause (instances in which shuttle operators are required to manually operate the shuttle):

- There was a total of 171 shuttle disengagements in November. Most disengagements were attributed to activity on the island by "Other Road Users", which is attributed to road work occurring on the island in week 3. In addition, the first instances of disengagements due to "Priority Zone" occurred, which will be monitored and further investigated in future reports.

Lastly, there were also more signal loss events than prior months, which is discussed further below in the “Map 1” notes.

Chart 6 — Incidents by Cause (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event):

- No incidents were reported in November.

Chart 7 — Ridership by Shuttle (total boarded passengers, recorded by shuttle):

- With the introduction of multiple shuttles, ridership was shared among the vehicles throughout the month. The drop in ridership for the week 3 can be explained by road work activity on the island.

Chart 8 — Disengagements by Shuttle (instances in which shuttle operators are required to manually operate the shuttle, recorded by shuttle):

- Most disengagements were observed on shuttle P66 with the highest concentration in week 3, as expected.

Chart 9 — Incidents by Shuttle (instances in which the shuttle is involved in a near miss, collision, or otherwise notable safety event, recorded by shuttle):

- No incidents were reported in November.

Chart 10 — Service Miles by Shuttle (total miles traveled while providing service to passengers, recorded by shuttle):

- A total of 1178 service miles were recorded in November. While this represents an increase from prior months, it is expected since multiple vehicles were running simultaneously throughout the month. Shuttle P32 and P66 recorded the bulk of the service miles since P84 was out of service during the first 3 weeks of the month.

Chart 11 — Service Hours by Shuttle (total hours of service provided to passengers, recorded by shuttle):

- A total of 419 service hours were recorded in November. Shuttle P32 and P66 shared most of the service hours, as expected.

Table 1 – Survey Response Tracking (summary of survey respondents monthly and since the start of the pilot)

- There were 9 survey respondents in November. Of these, 5 identified as riders and 4 identified as non-riders.

Table 2– Service Uptime (the ability for the vendor to provide on-going passenger service, based an expected level of service 9AM-6PM daily)

- In November, the vendor was able to provide passenger service 93% of the time (based on expected time traveled). Because headways were faster than the 27-minute goal during the last three weeks, the vendor was also able to achieve 106% of their expected runs (based on expected loops around the island).

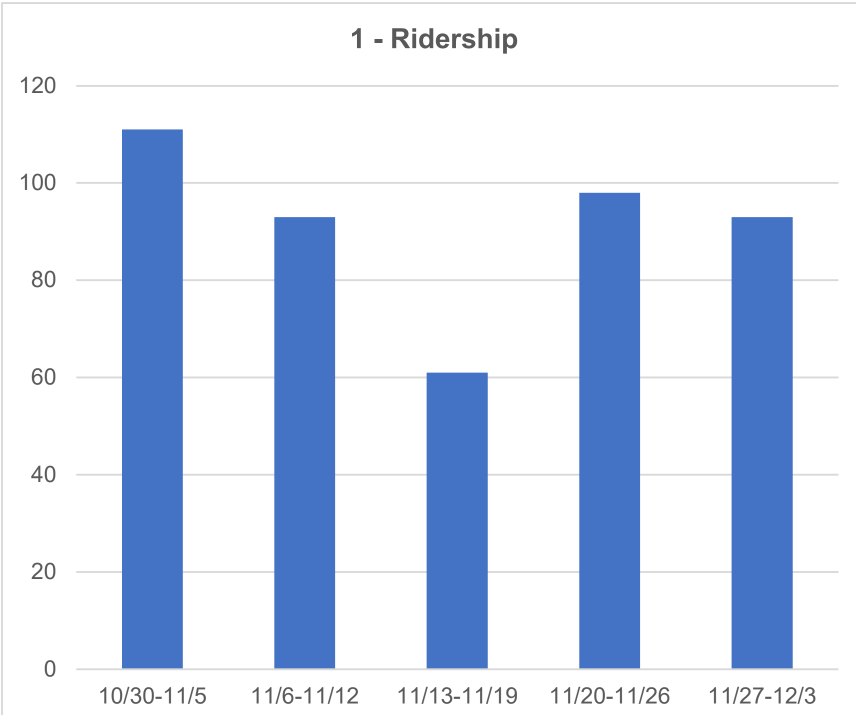
Table 3 — Additional Service Metrics

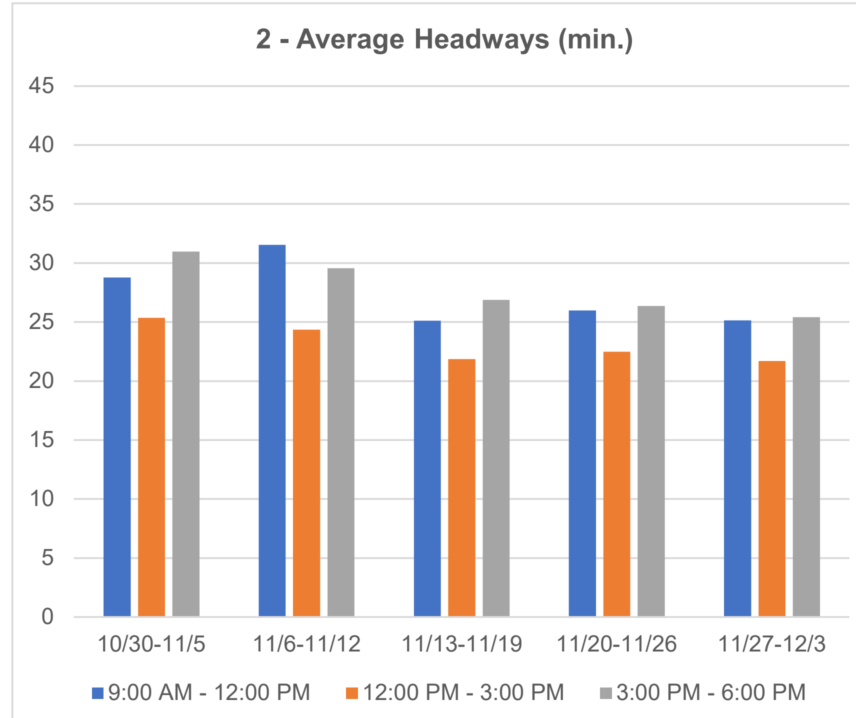
- There were 11 reported ramp deployments and 0 reported wheelchair securements for the month.
- Average Ending Battery % (the average battery life recorded at the end of an attendant's shift) showed there were no issues with battery usage or charging for any week or vehicle in November. With several vehicles in use, average ending battery life consistently stayed above 75%.
- There were no incidents, therefore incidents per mile were recorded as zero.
- While shuttle P66 appears to have a higher number of disengagements per mile, this trend has not been seen in prior months. This will be evaluated further in future months.

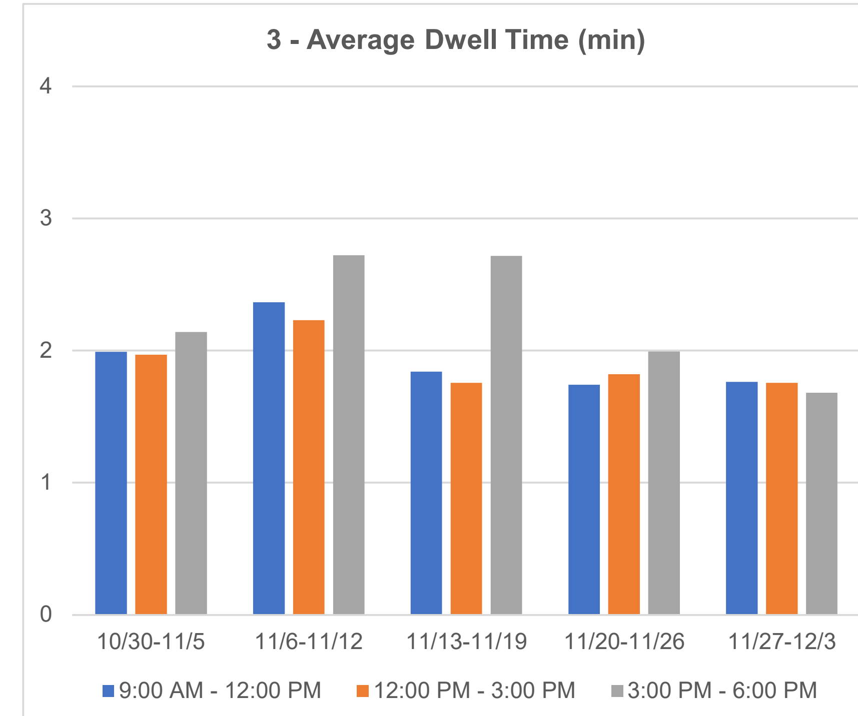
Map 1 — Reported Signal Losses

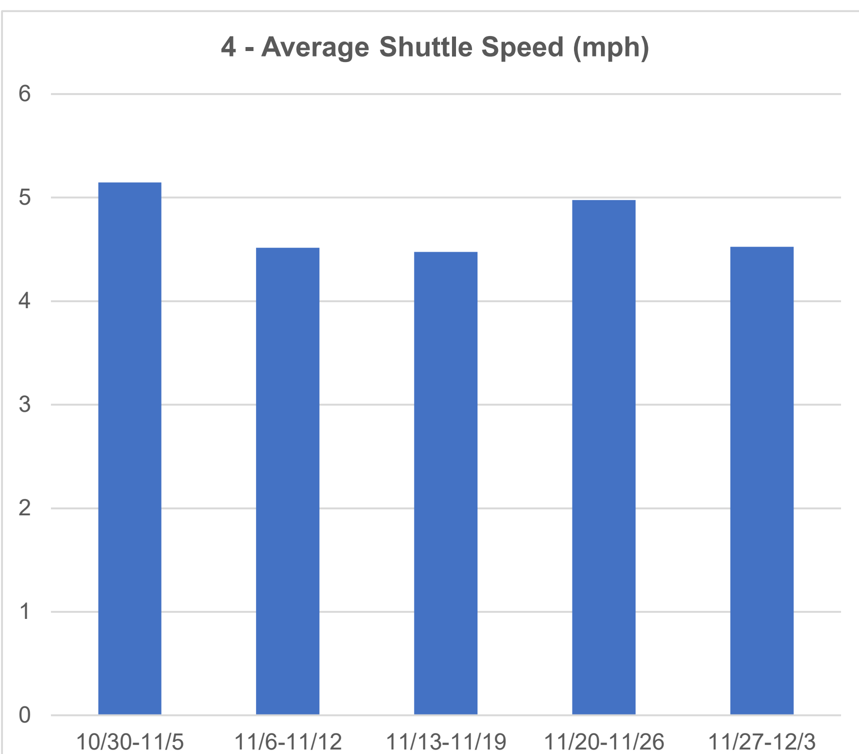
- There were 20 reported signal losses in November. As observed previously, there appears to be a pattern of signal losses at the Ship Shape Community Center. This will continue to be monitored in future reporting.

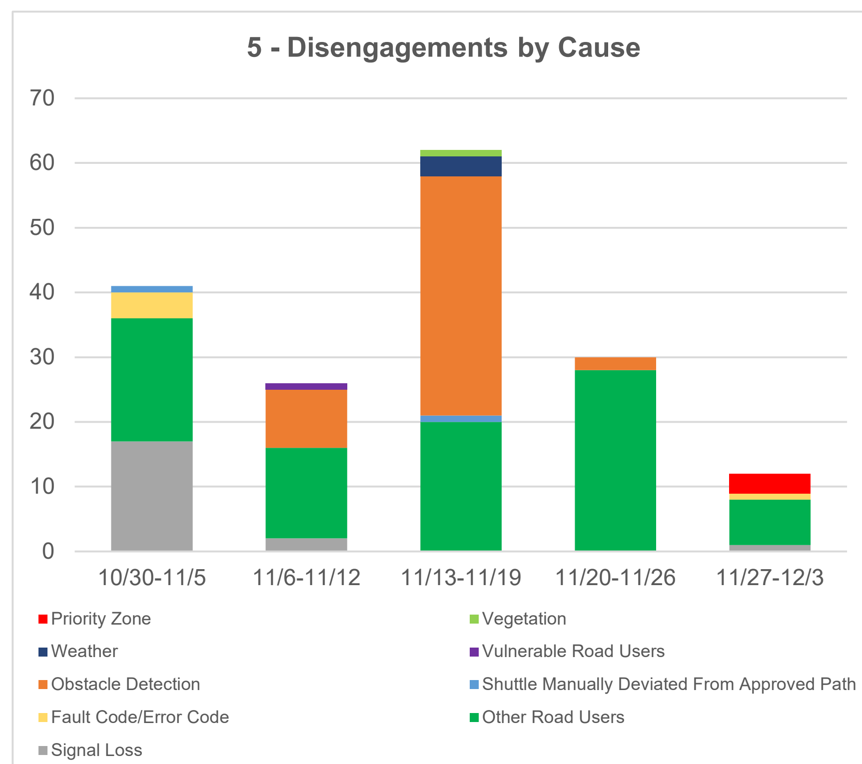
Monthly Summary Dashboard (November)

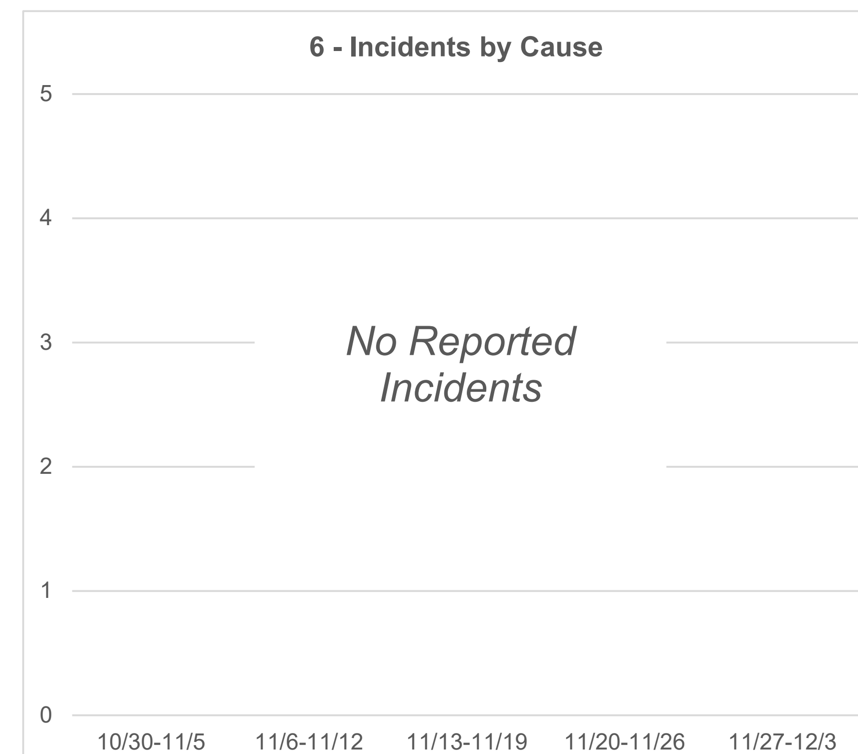








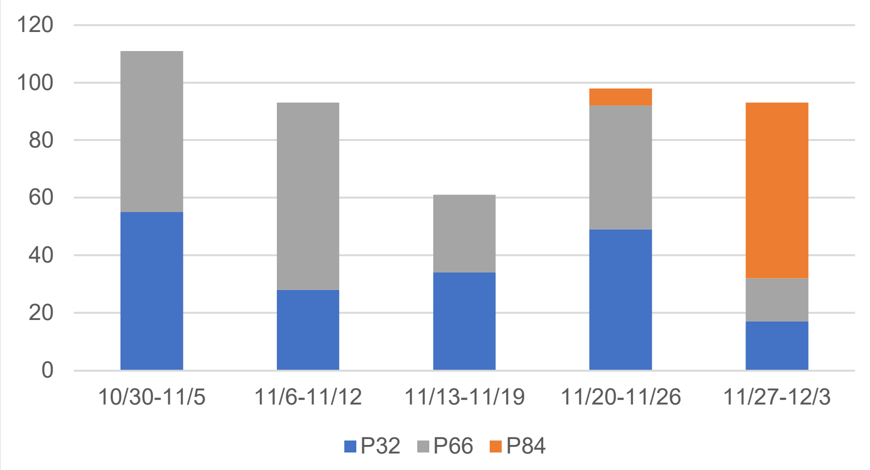




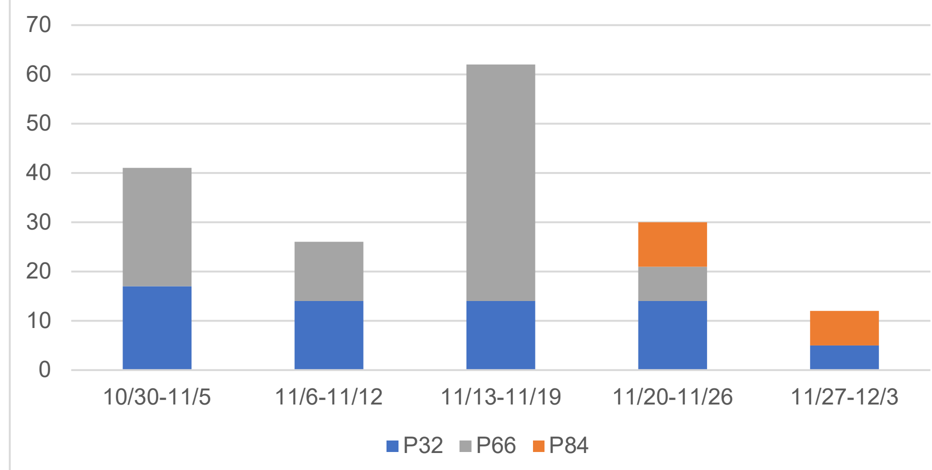
Summary of Incidents Involving First Responders: N/A

Monthly Summary Dashboard (November)

7 - Ridership by Shuttle

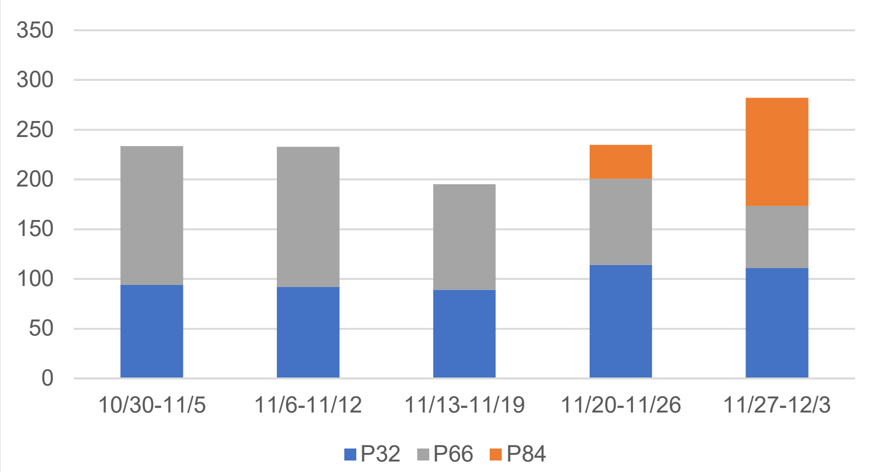


8 - Disengagements by Shuttle

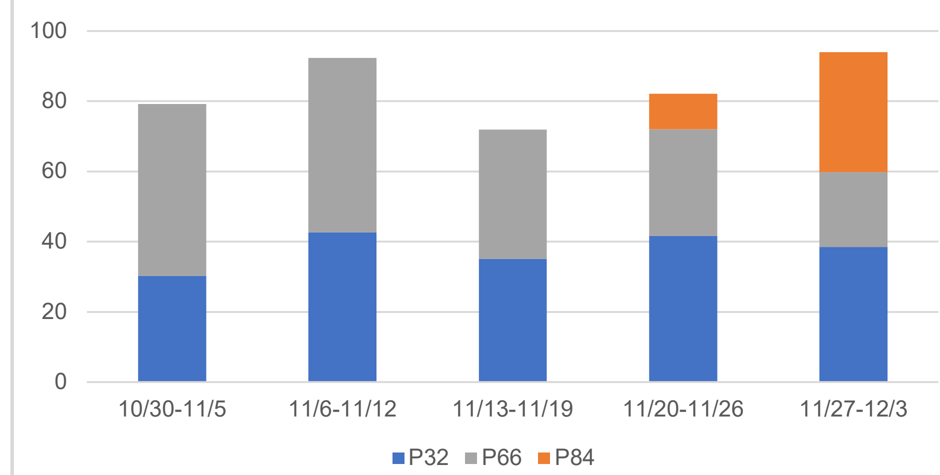


9- Incidents by Shuttle

10 - Service Miles by Shuttle



11 - Service Hours by Shuttle



Map 1 - Reported Signal Losses

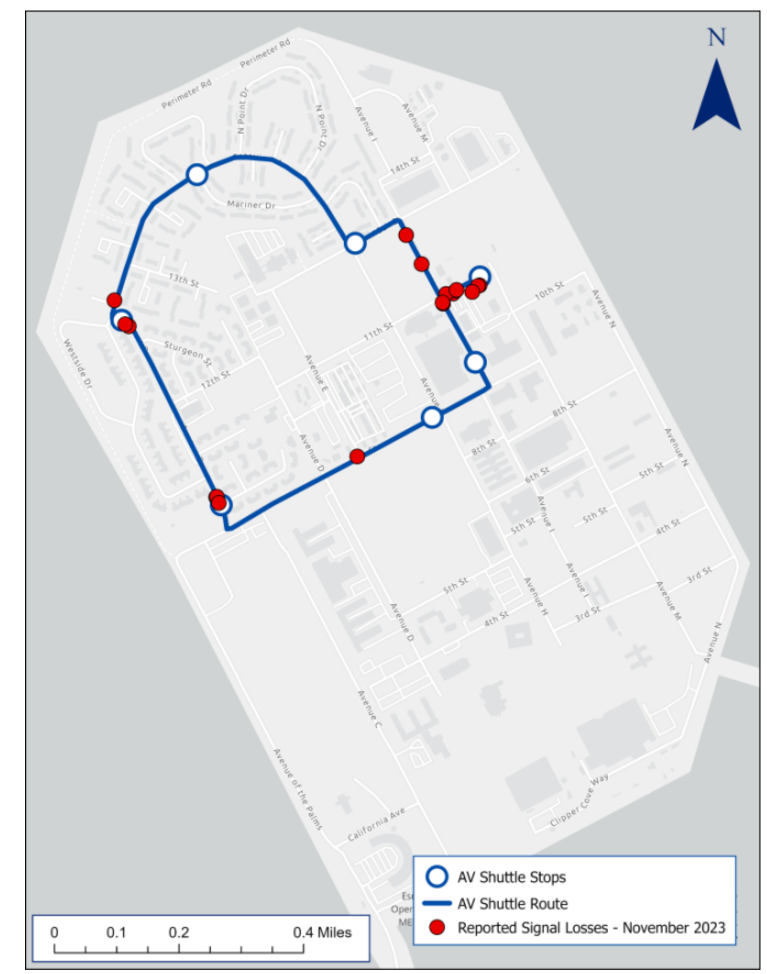


Table 1 - Survey Response Tracking

Monthly Reponses	Monthly % (Rider/Non Rider/NA)	Total Responses	Total % (Rider/Non Rider/NA)
9	56% / 44% / 0%	79	41% / 39% / 20%

Table 2 - Service Uptime

% Time Traveled	% Runs Completed
93%	106%
Exception for Hours *	**Exception for Runs ***
10	22

Table 3 - Additional Metrics

Week	Ramp Deployments	Wheel Chair Securements	Avg. Ending Battery %	Incidents / Mile	Disengage. / Mile
10/30-11/5	5	0	76	0	0.175
11/6-11/12	0	0	77	0	0.112
11/13-11/19	1	0	83	0	0.318
11/20-11/26	2	0	82	0	0.128
11/27-12/3	3	0	83	0	0.043
Shuttle					
P32	2	0	82	0	0.128
P84	3	0	85	0	0.112
P66	6	0	77	0	0.170

* Exceptions Given for Service Uptime: 11/23 was Thanksgiving and service was not provided. This accounted for 10 hours and an estimated 22 runs.

Attachment 3

TREASURE ISLAND
MOBILITY MANAGEMENT AGENCY

TC061124 RESOLUTION NO. 24-03

RESOLUTION ACCEPTING THE TREASURE ISLAND AUTONOMOUS VEHICLE SHUTTLE PILOT PROJECT FINAL REPORT

WHEREAS, In 2016, the San Francisco Municipal Transportation Agency (SFMTA), Transportation Authority, and other local partners together won an Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant from the US Department of Transportation, also known as the "Smart City" grant, administered by the Federal Highway Administration; and

WHEREAS, The grant program sought to showcase technology solutions aimed at reducing traffic congestion and creating safer and more efficient transportation systems; and

WHEREAS, The Treasure Island Mobility Management Agency (TIMMA) partnered with SFMTA to propose testing and deployment of shared Autonomous Vehicles (AVs) on Treasure Island; and

WHEREAS, The Treasure Island Autonomous Vehicle Shuttle Pilot Project (Pilot), called the "Loop" was a demonstration of an AV shuttle serving Treasure Island with a goal to demonstrate clean, shared, and accessible first/last-mile AV shuttle transportation on Treasure Island, and to assess technical performance and public perceptions of the innovative service; and

WHEREAS, The TIMMA Board approved the award of a contract to Beep, Inc. (Beep) to operate the AV shuttle in October 2022; and

WHEREAS, The Pilot was planned to operate for nine months, through spring 2024, and concluded early (January 2024) due to changing roadway configurations on the island; and

WHEREAS, The duration of service provided fulfilled the requirements of the federal ATCMTD grant and was the basis for an evaluation of the Pilot; and

WHEREAS, The Treasure Island AV Shuttle Pilot Project Final Report includes a detailed discussion on the Pilot's preparation, deployment, data analysis and findings, and community engagement and partnership efforts; and

WHEREAS, Acceptance of this final report does not have a financial impact; and

WHEREAS, Due to the early termination of the pilot, remaining funds from the federal Innovative Deployments to Enhance Arterials Shared Automated Vehicles grant will be returned to MTC; now, therefore, be it

RESOLVED, The TIMMA Board accepts the attached Treasure Island Autonomous Vehicle Shuttle Pilot Project Final Report.

Attachment:

1. The Loop Final Evaluation Report (Draft)