Wheels on the Bus Report

WHEELS ON THE BUS—REAL-TIME DATA PROJECT

FINAL IMPLEMENTATION REPORT

SANTA CLARA VALLEY TRANSPORTATION AUTHORITY

PERIOD OF PERFORMANCE: SEPTEMBER 2023 TO JULY 2025

PREPARED BY WSP

REPORT/FAIN NUMBER: 69A3552341049

AUGUST 2025

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

ADA	Americans with Disabilities Act
AI	artificial intelligence
APC	automatic passenger counter
API	application programming interface
AWS	Amazon Web Services
BCA	benefit-cost analysis
CAD/AVL	Computer Aided Dispatch/Automatic Vehicle Location
CCTV	close-circuit television
DOJ	Department of Justice
FTA	Federal Transit Administration
GPIO	general-purpose inputs/outputs
GPS	global positioning system
GTFS	General Transit Feed Specification
GTFS-RT	General Transit Feed Specification Real-time
HIL	hardware-in-the-loop
IIJA	Infrastructure Investment and Jobs Act
ITS	intelligent transportation systems
IVN	Intelligent Vehicle Network
KPI	key performance indicator
MDT	mobile data terminal
OCC	Operations and Control Center
OEM	Original Equipment Manufacturer
PDT	Project Development Team
Project	Wheels on the Bus—Real-time Data Project
SMART	Strengthening Mobility and Revolutionizing Transportation
TCRP	Transit Cooperative Research Program
USDOT	U.S. Department of Transportation
VTA	Santa Clara Valley Transportation Authority

Acknowledgements

Project Development Team
Ian Lin
Lauren Ledbetter
Adam Burger
Camille Williams
Gretchen Baisa
Jolene Bradford
Lalitha Konanur
Lisa Vickery
Manjit Chopra
Maya Esparza
Rachelle Tagud
Steven Chi
William Jochum

Consultant Team, WSP
Matt Baratz
Severin Skolrud
Kay Cheng
Armon Keshmiri
Mikaela Sword
Charvi Gupta
Tanay Gupta
Mingyang Li
Michelle Bisceglia
Cameron Kees
Shuai Wang

Vendors/Project Partners
Sportworks
Q'Straint
alwaysAI
Clever Devices
Swiftly

Revision Tracker

Date	Rev	Submitted by	Note
4/4/25	1.0	Kay Cheng	First draft with outlines across sections, including highlights in the executive summary to inform committee memos.
4/9/25	2.0	Tanay Gupta	Updated draft, expanding across sections, including 3 - hardware prototyping, 4 - reporting, 5 - deployment readiness, among others.
5/23/25	3.0	Lauren Ledbetter	Final draft with first round of VTA comments, added graphics, template, and finalized outline.
5/30/25	4.0	Tanay Gupta	Updated draft with details in 3 – hardware prototyping, design graphics, and added compliance for SMART, among other changes.
7/3/25	5.0	Tanay Gupta	Near final draft, ready for USDOT, pending any fatal flaws and sharing a clean and marked version with comments.
7/30/25	6.0	Tanay Gupta	Final draft report.
8/31/25	7.0	Ian Lin	Final report for VTA's submission to USDOT.

Wheels on the Bus Report

Chapter 1:
Executive Summary

1. Executive Summary

1.1 Introduction

Santa Clara Valley Transportation Authority's (VTA) Wheels on the Bus—Real-time Data Project (the Project) aims to address the problem of riders who travel with bicycles or wheelchairs/mobility devices being denied boarding because there is no room for their wheels on the bus. The Project seeks to collect occupancy data for bus-mounted bicycle racks and priority seating areas with sensors and share occupancy data in real-time so that these riders can make more informed decisions about when or whether to take transit. Such technology would also allow for automated data collection about bicycle and wheelchair use on transit and could shed light on occupancy patterns that inform transit trip planning. Riders who travel with bicycles or by means of a wheelchair or mobility device account for around 10 percent of all VTA passengers, but data is lacking about their trip patterns and the impact that the potential for being denied boarding has on their travel choices.

The Project is funded by a Stage 1 grant from the U.S. Department of Transportation (USDOT) Strengthening Mobility and Revolutionizing Transportation (SMART) Grant Program. Work consisted of researching multiple potential technologies for measuring occupancy, engaging with potential users, piloting hardware and software technologies on a single bus, and partnering with VTA staff to assess the feasibility of wider application.

1.2 Stakeholder Outreach

Stakeholder outreach consisted of meetings, focus groups, and interviews with members of the bicycling and disabled communities. While both types of users welcomed having access to occupancy data, they differed in how they envisioned its value.

Bicyclists envisioned the availability of real-time occupancy data to be useful, as it could inform a decision about whether to wait for the bus, ride to the destination, or ride to an alternate bus route.

Those who use wheelchairs/mobility devices envisioned that real-time data would be of little benefit, as they would not have much option other than waiting for the next bus. These riders are aware that they may be denied boarding and often allow extra time for traveling, in case they must wait for a later bus or encounter a delay. Rather than consult real-time occupancy data, they would be interested in accessing historical occupancy patterns, which could be an input in their trip planning.

1.3 Data Collection Methods Explored

Two project tracks emerged: one for measuring bike rack occupancy and one for measuring priority seating area occupancy. Each track would follow a similar information chain. Data collected by sensors would need to be transmitted through an onboard communication system to an online data portal where it could be accessible to the public or third-party apps.

Bicycle Rack Track

Collecting occupancy data for bicycle racks was straightforward since the Sportworks front-mounted bicycle racks on VTA buses include occupancy sensors, though VTA had not yet started collecting this data. VTA envisioned transmitting the data via its Clever Devices CAD/AVL system (the system that tracks the bus location and connects the operator to the operations control center), but the project team was unable to work out an arrangement with Clever Devices staff within the period of performance. The team opted to bypass Clever Devices CAD/AVL and pivot to using Velolink, a system made by Sportworks, that contained a mobile device for transmitting data.

Priority Seating Area Track

Collecting occupancy data for priority seating areas proved difficult as several uses occur in those spaces. VTA's policy is that disabled users have priority use of the space, but that conflicts with another policy to keep the center aisle clear. Riders with strollers or carts have no choice but to occupy the priority seating area, which can result in denied boardings for riders in wheelchairs/mobility devices. Non-disabled riders can also sit in the priority seating areas, and while some would gladly move to accommodate a wheelchair boarding, operators cannot force anyone to move. This presented two challenges: (1) whether a sensor(s) can accurately measure all the different ways the space can be occupied, and (2) whether the presence of a person or object in the priority seating area constitutes it being unavailable.

The project team considered several sensor types: bench seat up/down sensor, automatic passenger counter, wheelchair restraint tensioner, and camera-based AI computer vision software, ultimately testing the latter two. The team also looked at data sources like ramp deployments and manually-entered operator punch codes when disabled boardings occur. The wheelchair restraint tensioner showed promise for collecting occupancy data specific to wheelchairs and mobility devices only. The AI computer vision software testing was limited to using a model trained to recognize people in a sample of video footage. The sample included short clips retrieved from VTA's onboard camera that captured passengers in the priority seating area. A more thoroughly trained AI model coupled with superior image quality could be a singular solution for measuring occupancy, though perhaps not availability. Ultimately, no combination of sensors and information that the project team tested could provide a completely accurate assessment of priority seating area occupancy.

Transmitting sensor data through an onboard system proved challenging. The Clever Devices CAD/AVL system was limited by the number of data input ports on the IVN unit. This restricted how many sensors could feed data into the system. The Velolink system emerged as an alternative data transmitter.

1.4 Benefit-Cost Analysis

Additionally, during Stage 1, the project team outlined a framework for a benefit-cost analysis (BCA) to help VTA quantify the return on investing in occupancy data technology. This BCA details costs by vendor and technology. Benefits covered those that are passenger-facing (for example, fewer denied boardings and improved trip planning) and those internal to VTA. If VTA were to apply for a Stage 2 SMART Grant, the effort would include preparing a complete BCA with metrics such as the break-even year, multiple cost scenarios, and the number of buses retrofitted.

1.5 Looking Ahead

With Stage 1 complete, this project now has demonstrated, for the first time in North America, the viability of collecting real-time priority seating area and bike rack occupancy. With this foundation, Stage 2 could expand data collection and real-time occupancy tracking across more routes, while addressing key cost considerations—such as scalability, technology evolution, funding strategies, and benefit-cost refinement—to support a strong return on investment and long-term implementation strategy.

Valley Transportation Authority

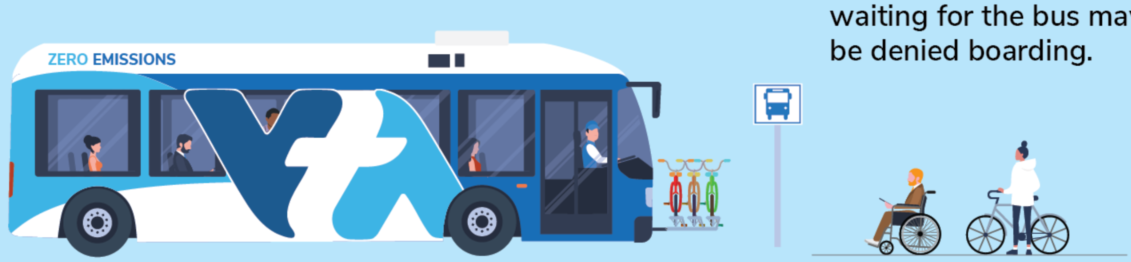
Wheels on the Bus

Existing conditions: (Without Sensors)

No data available on bike rack & priority seating occupancy

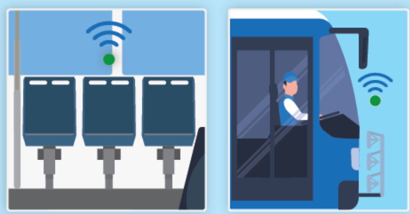
The Problem:

When these spaces are occupied, people waiting for the bus may be denied boarding.

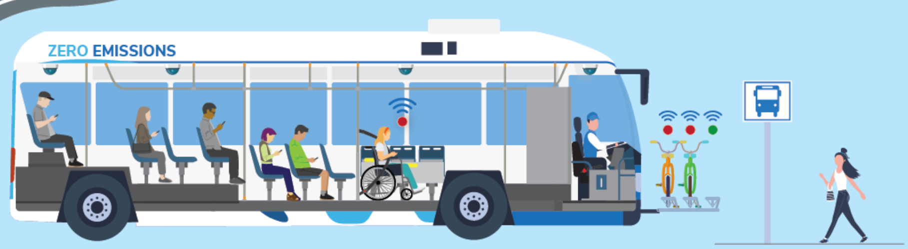


How WOTB is addressing the problem:

The project team spoke with people who regularly take bicycles and mobility devices onboard fixed route VTA buses to understand their experience of pass-ups, how real-time data could factor into trip planning, and how riders would prefer to receive real-time occupancy data.



Phase 1 Pilot: (With Sensors)



Project Benefits:

This new occupancy data (both historic and real time) will also allow VTA to proactively plan ways to **reduce or eliminate denied boardings.** This project will help to improve the experience for customers using mobility devices and bicycles.

Anticipated Outcomes:

- **Customers are informed in advance** if an approaching bus has room for them
- **Riders are able to notify VTA** that they need space on the bus
- **VTA is alerted in advance** if a pass-up situation may occur and can proactively address the problem

Wheels on the Bus Report

Chapter 2:

Introduction and Project Overview

2. Introduction and Project Overview

2.1 Project Description

The Wheels on the Bus—Real-time Data Project (the Project) explores whether transit agencies can reduce denied boardings caused by a lack of space for wheelchairs or bikes by providing passenger with real-time occupancy information for priority seating areas and bus-mounted bike racks.[1] The Project is funded by a Stage 1 grant from the U.S. Department of Transportation (USDOT) Strengthening Mobility and Revolutionizing Transportation (SMART) Grant Program.

This report describes the first stage of a two-stage grant program, referred to as Stage 1 and Stage 2 throughout this report. Stage 1 grants are for planning and prototyping (this Project), while Stage 2 grants are for implementation. USDOT selects a subset of Stage 1 recipients to receive Stage 2 awards based on a competitive application; therefore, not guarantee a second stage.[2] If VTA were to receive a Stage 2 grant, the project would implement real-time data collection on a larger fleet of buses and conduct a cost-benefit analysis of expanding to the entire fleet. Ultimately, VTA would like to help passengers reliably bring their "wheels"[3] on board VTA buses.

2.1.1 General Problem Statement

VTA is an independent special district that provides sustainable, accessible, community-focused transportation options, including bus, light rail, and paratransit services in Santa Clara County, California.[4] With approximately 92 million passenger miles traveled annually, VTA operates 330 buses on 44 regularly operating routes, including 3 light rail

---

[1] "Occupancy" refers to the occupancy of bike racks and ADA priority seating areas, unless stated otherwise. This occupancy is different from automated passenger counting (APC) systems, which count the number of all passengers, a mainstream technology in the industry.

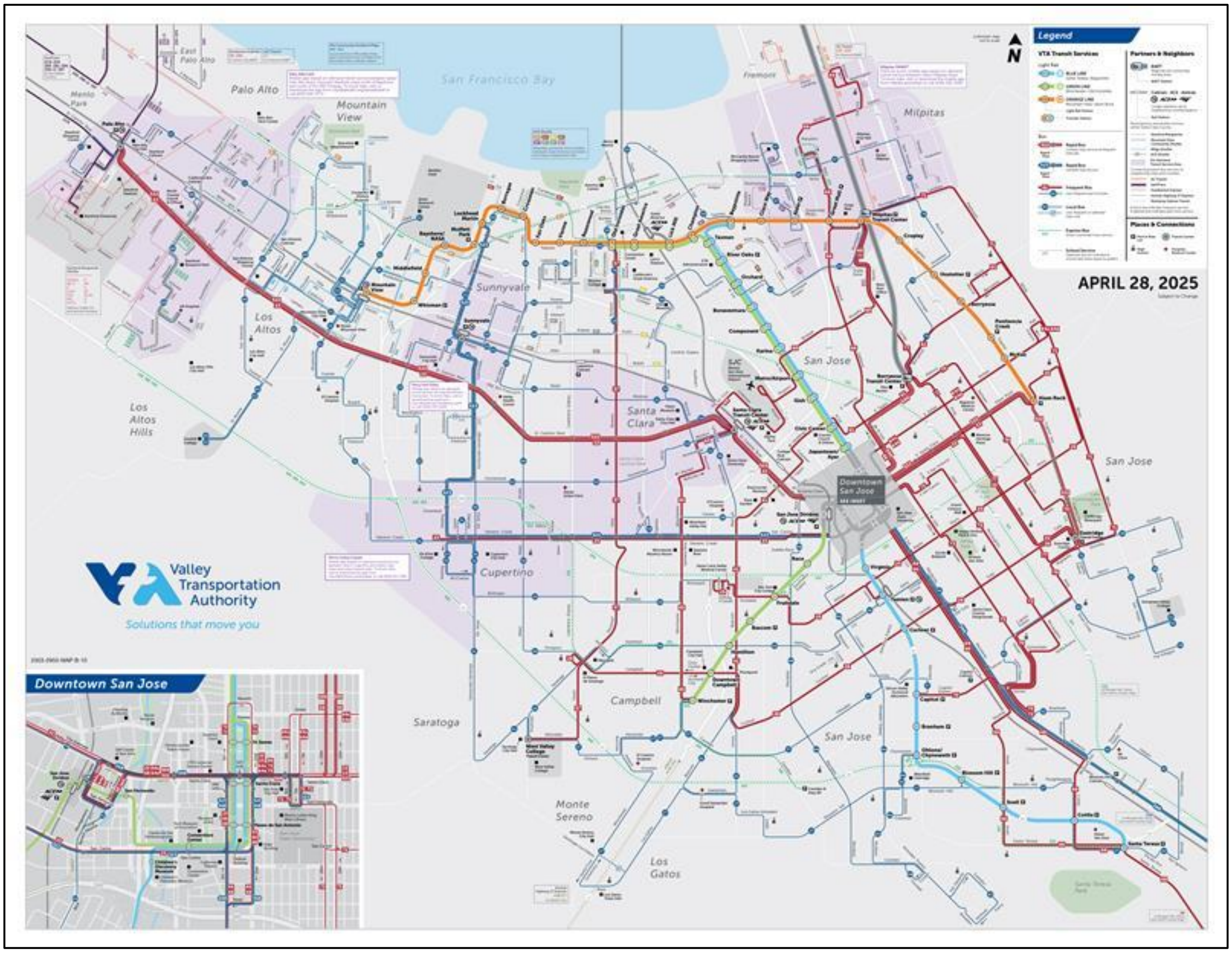
[2] This report phrases Stage activities with certainty (i.e. "Stage 2 will investigate how to enable real-time occupancy"). While the decision to proceed forward is still pending as of this writing, the report aims to outline intended next steps if VTA pursues and is awarded Stage 2 DOT funding.

[3] "Wheels" refers to bikes, wheelchairs, pushcarts, strollers, scooters, or any other device with wheels that passengers can bring onboard VTA buses. The Project focuses specifically on reducing denied boardings for passengers with bikes and wheelchairs.

[4] Santa Clara Valley Transportation Authority (www.vta.org/about).

routes, 4 rapid bus routes, 16 frequent routes, and 21 local routes in the 346-square-mile service area (Figure 2-1.).[5]

Figure 2-1. VTA Service Area



Source: VTA 2025

Denied boardings plague all transit users and bus operators; however, there is no solution for reducing them. Denied boardings are disruptive and frustrating for passengers and can discourage transit use, potentially reducing passengers' freedom to travel. Additionally, managing denied boarding for wheelchair users presents operational challenges.

[5] VTA National Transit Database Annual Agency Profile 2023 (https://www.transit.dot.gov/sites/fta.dot.gov/files/transit_agency_profile_doc/2023/90013.pdf).

For example, at VTA, when bus operators must deny boarding a wheelchair user, they must pause their route and contact the Operations and Control Center (OCC) to inquire if the trailing bus has occupancy and assess how soon the next bus will arrive. If the wait is estimated to be more than 20 minutes, a field supervisor must be dispatched to provide a direct ride for the passenger who was denied boarding. This check-in with OCC involves multiple radio calls and can last multiple minutes, delaying the route. Additionally, denied boardings can place bus operators in confrontational situations with passengers, a dynamic that bus operators seek to avoid.

VTA lacks reliable data about priority seating areas and bike rack usage. Metrics such as wheelchair ramp deployments can paint a partial picture, but they are inadequate because they also capture boardings for strollers, carts, and anyone who needs help stepping up onto the bus. These metrics also fail to count passengers with disabilities who use the priority seating areas but who do not need ramp assistance to board.

Additionally, information about denied boardings for passengers with bikes comes only from anecdotal accounts, which may underrepresent the scope of the issue. Automated collection of occupancy data would offer a richer and more accurate understanding of how both priority seating areas and bike racks are used. This insight could help inform service planning and lead to more efficient bus interior configurations.

To address these challenges and improve the rider experience, VTA can explore the following strategies:

- Use on-board sensors to collect real-time occupancy data for priority seating areas and bus-mounted bike racks.
- Help passengers reliably bring their “wheels”[6] on board VTA buses.
- Make occupancy data available to passengers in real time through mobile apps, the transit agency website, or customer service call centers so they can know in advance if an approaching bus has room for their wheelchair or bike.
- Allow customers to notify VTA that they need space on the bus.

[6] “Wheels” refers to bikes, wheelchairs, pushcarts, strollers, scooters, or any other device with wheels that passengers can bring onboard VTA buses. The Project focuses specifically on reducing denied boardings for passengers with bikes and wheelchairs.

- Alert VTA in advance if a denied boarding situation may occur, thereby allowing VTA to proactively address the problem.

2.1.2 Technical Elements

Per SMART grant guidelines, the Project is focused on improving a transportation system using high-tech sensors, closed-circuit television (CCTV), and real-time software. Specifically, the project team aimed to use the tools, including Clever Devices, Sportworks, and VTA servers, to create a more efficient and passenger-friendly experience for those who bring “wheels” on board VTA buses.

The methods used to collect data about bike rack occupancy and priority seating area occupancy differ from one another. For this reason, the project team explored different methods for each area.

Collecting Bike Rack Occupancy Data

At the start of the Project, the bike racks on VTA buses were already equipped with sensors that could hypothetically detect occupancy, but the sensors were not connected, nor could the bike rack occupancy data be transmitted to any system. Because bikes are the only objects allowed in the bike racks, and the racks can only be in occupied or non-occupied states, collecting and evaluating this data is straightforward. For more information about the methods used, see Section 3.5, *Sensor Implementation*.

Collecting Priority Seating Area Occupancy Data

VTA buses do not provide dedicated space for wheelchair users, but instead provide a priority seating area with fold-up bench seats. Since the priority seating area is a shared space, collecting occupancy data is complicated. Although priority is given to wheelchair users, priority seating areas can be occupied by different types of people or objects, variations referenced as “priority seating scenarios.” These scenarios refer to the full range of ways the priority seating area may be used or occupied (by people using wheelchairs, strollers, carts, standing passengers, or individuals with limited mobility), each requiring distinct detection methods.

For example, the bench seat may be in the up position and occupied by wheelchair users or those using other mobility devices; however, the bench seat may also be in the down position, and the space may be used by ambulatory passengers. The space can also be used by any passenger to temporarily store strollers or small carts out of the aisle. Since these scenarios can occasionally result in a customer with a wheelchair being denied boarding, the project team wanted to explore ways to measure them as well as the simpler scenario of a wheelchair occupying the priority seating area.

VTA bus operators manually record when wheelchair users get on and off the bus by entering a specific code in their mobile data terminal (MDT), a touchscreen unit in the bus operator's compartment that they use to communicate with dispatch and monitor other systems on the bus.

However, this method of collecting data does not capture the use of the priority seating area by ambulatory passengers or passengers using the area to store strollers and carts. This gap in the recorded data makes finding a method that can account for all use scenarios difficult, and the project team has explored a variety of technologies that could be used. For more information, see Section 3, *Prototyping*.

2.1.3 Project Goals and Objectives for At-scale Implementation

Table 2-1 lists the project goals and objectives as they align with the statutory areas outlined in the Infrastructure Investment and Jobs Act (IIJA).

These objectives are focused on supporting wheelchair users and those who bring bikes on VTA buses by improving their decision-making capabilities, thereby improving the quality of their journeys on VTA buses.

Table 2-1. Alignment with Statutory Goal Areas from the IIJA

Goal Area	Objective
Accessibility	Improve the customer service experience for some of the most vulnerable passengers, including bicyclists and wheelchair users, by providing VTA with the means to provide customers with real-time bike rack and priority seating occupancy information.
Reliability	Improve the reliability of passenger information by providing real-time data about bike rack and priority seating area occupancy, thereby reducing denied boardings.
Integration	Promote connectivity between the VTA transit network and the existing bike infrastructure in Santa Clara County for multimodal trips with transfers between bicycling and transit.
Partnerships	Incentivize investments or partnerships with private sector vendors and data providers.

2.2 Community Impact

The Project aims to make transit use more accessible for bicyclists and passengers who have disabilities. Improving accessibility would also improve connections between people and improve access to jobs, education, medical treatment, and other essential services. The project team explored solutions that would expand access for underserved or disadvantaged communities and improve the reliability of traveling by VTA bus.

According to VTA's 2024 On-Board Customer Survey, 3.5% of passengers ride a bike to their bus stop, and 4.5% of bus customers have a disability. When combined, these two communities represent almost 10% of VTA passengers.

This section summarizes the outreach to passengers and VTA stakeholders to understand if real-time data can benefit passengers who rely on VTA's fixed-route bus service. Through these discussions, ideas were also raised about how data collected as part of this project could be used by VTA to optimize route schedules to better serve passengers. The outcomes from this Project have the potential to improve transit reliability and customer experience for users who depend on transit to access basic services and facilities.

For more about the ways that this Project could benefit passengers, see Section 4.3.1, *Passenger-Facing Benefits* .

2.2.1 Public Outreach and Stakeholder Engagement Strategies

Denied boarding for passengers with bicycles or mobility devices has not been studied in-depth, and VTA lacks reliable data and only hears from a subset of customers who have experienced denied boardings. Therefore, the project team facilitated conversations with the disabled community and bicyclists to understand how these communities are impacted by the lack of space on the bus and what factors to consider when developing an effective solution.

Key information that the project team sought to collect was around what denied boardings mean for their ability to travel, and how real-time data could improve trip planning. The feedback has informed the potential solutions VTA explored.

Table 2-2 shows the various strategies used to gather public feedback.

Table 2-2. Project Engagement Strategies and Attendance

Engagement Tactic	People Engaged	Target Demographic	Purpose
VTA Online Surveys	63	Bicyclists and passengers with disabilities	Feedback from target user groups (April to June 2024)
Focus Groups	13	Bicyclists and passengers with disabilities (separate focus groups)	To understand concerns through in-depth discussion on experiences
Pop-up Event at the Santa Clara Senior Resource Center	20 to 30	Senior citizens and passengers with disabilities	To collect feedback from people who organize transportation for seniors on their needs
VTA Internal Stakeholder Survey	8	Key VTA departments[1]	To identify priorities for prototype options (for example, cost, reliability, vendor agnostic, and so on)
Kitchen Table Talks	Tabled at Cerone Yard for 1 day	VTA bus operators	To understand the perspective of the operators on denied boardings, assisting passengers with mobility devices, feedback on project objectives, and other input on operational barriers
One-on-one Interviews with VTA Bicycle and Pedestrian Advisory Committee Members	1	Bicyclists and passengers with disabilities (separate focus groups)	To understand concerns through in-depth discussion on experiences
VTA Customer Service Complaint Log	936	Riders who experienced being denied boarding VTA's fixed-route buses	To analyze existing issues regarding denied boarding and identify potential causes of denied boarding.
Presentations to VTA Committees of the Board	10	Bicycle and Pedestrian Advisory Committee, Committee for Transportation Mobility and Accessibility, and local community leaders and representatives	To provide periodic project updates for feedback, guidance, and directions.

[1] Departments included Transportation Planning, Operations, Service Planning, Maintenance, and Community Outreach.

Figure 2-2 shows the project team's participation in a pop-up event at the Santa Clara Senior Resource Center to gain feedback from seniors with disabilities and caretakers who organize transportation for seniors.

Figure 2-2. VTA Discussion with Seniors about the Project

Source: WSP 2024

Apart from the public-facing outreach activities, the project team held monthly discussions with the VTA Project Development Team (PDT), comprised of a cross-section of departments from operations, service planning, to community outreach.

The following sections summarize the key themes learned from the community and stakeholders.

2.2.2 Denied Boarding Experience

Among passengers who use mobility devices, 36% of survey respondents reported that they have been denied boarding at least once with their wheelchair or personal mobility device. When asked whether the potential to be denied boarding would make them less likely to take the bus, 40% of respondents responded “Yes,” and 46% responded that “It depends on the circumstances,” while the circumstances were not clearly defined.

In the focus group with bicyclists who regularly use transit, one out of nine participants experienced a denied boarding. A greater percentage of bicyclists who responded to the survey (29%) reported that they were denied boarding a VTA bus because of a full bike rack.

Due to the small sample size and the fact that participants self-selected, these rates should not be applied to the entire VTA system.

Survey and focus group participants expressed that denied boardings can cause greater inconvenience for passengers on local routes that have lower frequencies, because a denied boarding on these routes can result in a long wait time.

2.2.3 The Usefulness of Real-Time Occupancy Data

We asked the participants if real-time occupancy data would be helpful when waiting at a bus stop. We found that wheelchair users were less likely than bicyclists to see real-time occupancy data as a benefit. However, both groups felt historic occupancy data could be useful when planning a trip, noting that they could choose between different routes or times to pick the option that was most likely to have space on the bus.

Passengers with disabilities shared that they would use VTA service regardless of having access to real-time occupancy data, and they would not take an alternate course of action, such as taking a different bus route, if there were no space on the bus. Focus group participants noted that the trips they take are typically for appointments or non-discretionary travel and are planned well in advance. Once a trip is underway, there is little flexibility in what route or what time a customer needs to arrive at their destination, and so they may not be able to modify their trip in real time.

> Passengers with disabilities expressed that they would use VTA service regardless of having access to real-time occupancy data. However, historical occupancy data could inform their decision-making when planning trips using VTA.

However, these passengers were interested in how historical occupancy data could inform their decision-making when planning trips using VTA. This information could help a customer schedule an appointment at a time when the buses are more likely to have space.

Access to real-time data would be helpful for bicyclists when waiting for their bus because they have flexibility in adapting their trip if they are denied boarding. They can more easily ride to another stop on their route, a stop on a different route close by, or even complete their trip on their bikes, which in some cases may be faster than waiting for another bus.

Similar to the responses from passengers with disabilities, bicyclists noted that historic occupancy data could help them when planning their trip.

Two participants suggested that the low frequency of buses on routes could be a reason for denied boardings. Participants suggested that VTA could use historical data to identify routes that would benefit from increased frequency to reduce denied boardings.

2.2.4 How Would Passengers Prefer to Access Real-time Data If It Were Available?

Most focus group participants use apps, such as Google Maps and Transit App, to select a route and check bus schedules. Participants noted they often use both apps together to plan a route and confirm that the bus is still arriving on time. The project team asked participants how they would prefer to access real-time data. Several expressed that accessing real-time data would be most convenient if integrated into existing apps, such as Google Maps or Transit App, so they do not need to consult an additional platform or website.

During the focus group discussions, one participant also suggested that transit operators should consider making real-time data available in multiple formats rather than simply weighing one option against another. For example, real-time data could be displayed on digital screens at shelters and stations, available via customer service phone line, on apps, and on the VTA website to increase the likelihood of users accessing and benefiting from the data.

Another key takeaway from the focus group discussions was finding an equitable approach to scaling a technology solution. Participants expressed that VTA should ensure that information is available to all users regardless of their access to smartphones or apps, disability, age, or income. Participants noted that not everyone has access to a smartphone, some do not know how to use or download apps, and not all bus shelters have display screens to show real-time data.

The project team asked focus group participants to respond to a mockup of Transit App showing how priority seating occupancy data could be displayed. In the mockup, a green wheelchair icon indicates that priority seating areas are available, and a grayed-out icon indicates that priority seating areas are full (Figure 2-3).

The project team shared a similar mockup to show how Transit App could be used to share bike rack occupancy data. In the mockup, the bike icon indicates that bike racks are available, and a grayed-out bike icon indicates that bike racks are full (Figure 2-4).

These images were purely intended to facilitate discussion, recognizing that indications showing number of spots available and user interface design can be improved. Depending on the pathway selected to provide data to passengers, Stage 2 will include close collaboration with app providers to discuss feasibility.

Figure 2-3. Transit App Mockup (Priority Seating Occupancy)

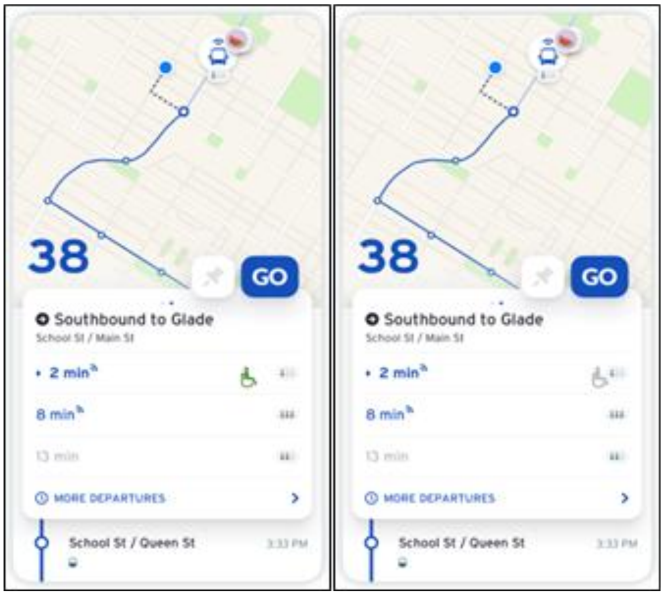
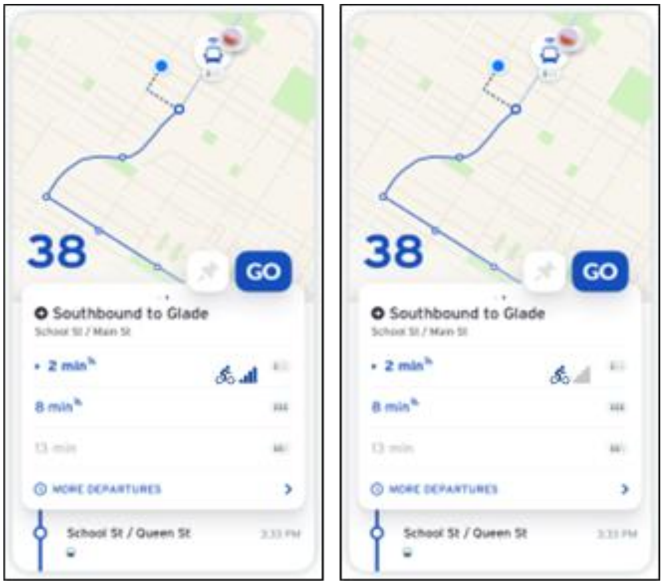


Figure 2-4. Transit App Mockup (Bike Rack Occupancy)



Source: Transit App with WSP edits, 2024

2.2.5 Passenger Complaints

> Logs from the VTA Call Center showed issues related to denied boardings caused by a lack of space. VTA can better understand and mitigate these incidents by: (1) collecting more detailed data about the causes of denied boarding; (2) implementing policy improvements, such as aligning standards for passengers and bus operators on boarding processes; and (3) providing occupancy data for bike racks and the priority seating areas (the focus of this Project).

The project team reviewed complaint data related to denied boardings for passengers with bikes, wheelchairs, or other mobility devices. This information is stored in the VTA Call Center database.[7]

One limitation of these data sets is that the complaints are self-reported by passengers and may not provide a full picture of why an individual was denied boarding. For example, many passengers who logged complaints could not identify why they were denied boarding. Additional research into the root cause of each incident (whether due to the operator, passenger, or a combination of factors) could uncover ways to reduce denied boardings. The next two subsections describe findings from call center complaint data for wheelchair users and bicyclists.

Wheelchair Users and Passengers with Disabilities

VTA received 936 complaints about denied boardings from passengers using mobility devices from 2019 to 2023. Several cases were reported of the bus being too full to allow them to board, creating significant delays for passengers who had to wait for the next available bus (some spent up to 3 hours of additional time waiting).

Other common issues included bus operators failing to see passengers waiting to board or passengers not receiving assistance with strapping into priority seating areas. However, many complaints lacked context from the operator’s perspective, particularly in instances where passengers were denied boarding without a clear reason. In these situations, it would be helpful to understand the operator's perspective, which could include lack of visibility at a stop, or prior confrontational interactions with a customer.

[7] While complaint data is not provided as part of the publicly available datasets from this project, this section aims to describe key insights relevant for this project.

Stage 2 of the Project would benefit from further engagement with operators, particularly regarding the following questions:

- What are some of the reasons you are unable to stop to pick up passengers? For example, overcrowding, running late, or safety concerns.
- How do you typically communicate to passengers that they cannot board because there is no room?

Bicyclists

VTA received 164 complaints about denied boardings from bicyclists from 2019 to 2023. However, for most complaints, it is unclear whether the buses failed to stop because of a lack of space. Common issues perceived by passengers included the following:

- Buses pulling away too quickly
- Bus operators not seeing passengers waiting to board at a designated stop
- Bus operators not allowing bikes through the rear doors of the bus

Key takeaways from the complaint log data include the following:

- **General Pass-up:** Most complaints cited that operators did not slow or stop for passengers. However, the passengers were left unclear on why the bus did not stop for them (that is, not because the bus was full or out of service).
- **Bikes not Permitted On Board:** Several complaints were logged about operators not allowing bikes on the bus, which prevented passengers from boarding.
- **Rapid Departure**: In some cases, operators departed the stop too quickly while passengers collected their bikes or other items. Operators did not wait for passengers to mount bikes on the bike racks, or did not allow enough time for passengers to board through the rear doors of the bus.
- **Full Bike Rack**: In a few instances, the bike racks were fully occupied; therefore, the operator did not stop.

- **Electric Bikes, Scooters, and Other Types of Bikes**: For passengers using electric bikes, electric scooters, or other types of bikes, a few complaints were logged that described these types of equipment not being allowed to be mounted on the bike racks or brought onto the bus.

2.2.6 Kitchen Table Talks with Operators

The project team sat in at the VTA Cerone Bus Yard in San Jose, CA for 90 minutes to talk with bus operators during their breaks. These discussions provided insight into the operational challenges and other factors that may contribute to denied boardings. The project team spoke with eight bus operators and identified the following considerations:

- Priority seating areas are often occupied by customer’s belongings, in addition to strollers and carts.
- More flexible seating areas on buses would help accommodate different needs, such as wheelchairs, strollers, and luggage.
- Operators are unsure how to address conflicting needs. For instance, sometimes there are senior passengers and disabled passengers who both require use of the same space. Are bus operators expected to move passengers not in wheelchairs but who also need to use the priority seating area? How should VTA keep bus operators from conflict while managing the limited space available and on-time performance pressure?
- VTA bus operators are trained to ask passengers who are not disabled to move from priority seating areas if a disabled user is attempting to board and use that space. However, they cannot require that anyone move seats. Language barriers, a preference to avoid confrontation, or a crowded bus without alternate available seats can be factors that contribute to a denied boarding despite an operator’s best attempt.
- Space is constrained on buses, and operators are trained to ensure the aisles are not blocked. Customers with carts, strollers, or large belongings may be using the priority seating area and cannot move without blocking the aisle.
- Real-time occupancy data for bike racks might be more beneficial for routes that serve commuters and major employment hubs. Specifically, being denied boarding on an express bus, which has long headways and makes long-distance trips only during peak periods, could mean not being able to travel at all.

- Increasing the number of articulated buses in use could help meet dynamic ridership demand.

2.3 Scale of Deployment

Stage 1 of the Project consisted of a pilot program to retrofit a single bus with technologies to collect bike rack and priority seating occupancy data.

VTA allowed the project team and vendors access to inspect and select a bus from buses 4401, 4402, and 4403, which are all 40-foot hybrid Gillig buses from 2014. Although these buses are slightly older, VTA uses them to test new technology. These buses operate in revenue service but are limited to the routes that operate out of VTA's Cerone Depot, where the buses are stored.

The project team's original implementations were performed on Bus 4403; however, partway through the Project, the project team determined that a bus with a newer wheelchair restraint system and a modern priority seating area would allow them to work more efficiently. For this reason, as the project team entered the system installation and testing phase, they moved operations to Bus 3402, which is a 40-foot hybrid Gillig bus from 2023. This change allowed the project team to simply drop in a replacement wheelchair front tensioner instead of having to retrofit a newer model tensioner on an old mount. Ultimately, all final occupancy detection configurations were implemented, tested, and operated in revenue service on Bus 3402 between January 2025 and May 2025.

2.4 Project Activities

Stage 1 of the Project spanned over a year and included evaluating multiple technologies, engaging with key stakeholders, piloting technologies, and partnering with internal departments to assess feasibility and next steps.

Figure 3-9 shows key milestones achieved during Stage 1. Additionally, Section 1, the *Executive Summary*, highlights the project's purpose, summarizes key findings from stakeholder outreach and technology evaluation, and next steps for Stage 2.

2.5 Media and Public Attention

As a first-of-its-kind prototyping project, this Project is expected to gain some media attention as this report concludes and Stage 1 is completed. So far, the project team has been focused on demonstrating technical feasibility through internal collaboration with partners and passengers. When Stage 1 is complete, the project team looks forward to showcasing its findings in conferences and other public forums.

2.6 Changes in Scope

The project team prototyped cost-effective, compact, and simple solutions within the constraints of the SMART grant's budget and timeline. These solutions included integrating with the VTA's existing Computer Aided Dispatch/Automatic Vehicle Location (CAD/AVL) system (Clever Devices Intelligent Vehicle Network [IVN]), a self-contained bike rack monitoring solution (Sportworks Velolink), and a CCTV-based artificial intelligence (AI) option (alwaysAI).

For tracking priority seating occupancy, the project team pivoted from testing a singular hardware technology solution to testing a variety of sensor technologies. The project team took this multiple-sensor approach because no single sensor could measure priority seating occupancy with 100% accuracy. It was anticipated that using multiple sensors simultaneously might result in the most accurate data.

The project team also aimed to demonstrate multiple commercially available solutions to provide options for agencies with varied systems and fleets, but due to budget and schedule constraints, the team was not able to test all solutions in the field. For example, the project team tested occupancy sensors on the hardware bench but could not fit a full field test of that solution within the schedule due in part to an unrelated labor action that suspended project activities for almost a month.

Wheels on the Bus Report

Chapter 3:
Prototyping

3. Prototyping

Stage 1 of the Project was a planning and prototyping effort and did not include implementing fleet-wide solutions. Rather, it explored challenges related to technology, operations, logistics, policy, and cost related to implementing a system-wide solution.

3.1 Technology Goals and Expectations

During Stage 1, the project team aimed to rapidly discover, develop, and iterate on various sensor or data systems that met the performance measures described in Section 3.3, *Performance Measures for Prototype*.

The project team tested physical and digital methods for collecting data in both controlled environments and active revenue service. Additionally, the project team explored several methods for transmitting data off the bus in real time and assessed the potential benefits of providing this data to passengers.

The project team focused on demonstrating the accuracy of information under varied conditions and the feasibility of collecting occupancy data on a day-to-day basis. This prototyping effort was crucial for validating hypotheses, uncovering potential pitfalls, and refining the approach if VTA should choose broader deployment.

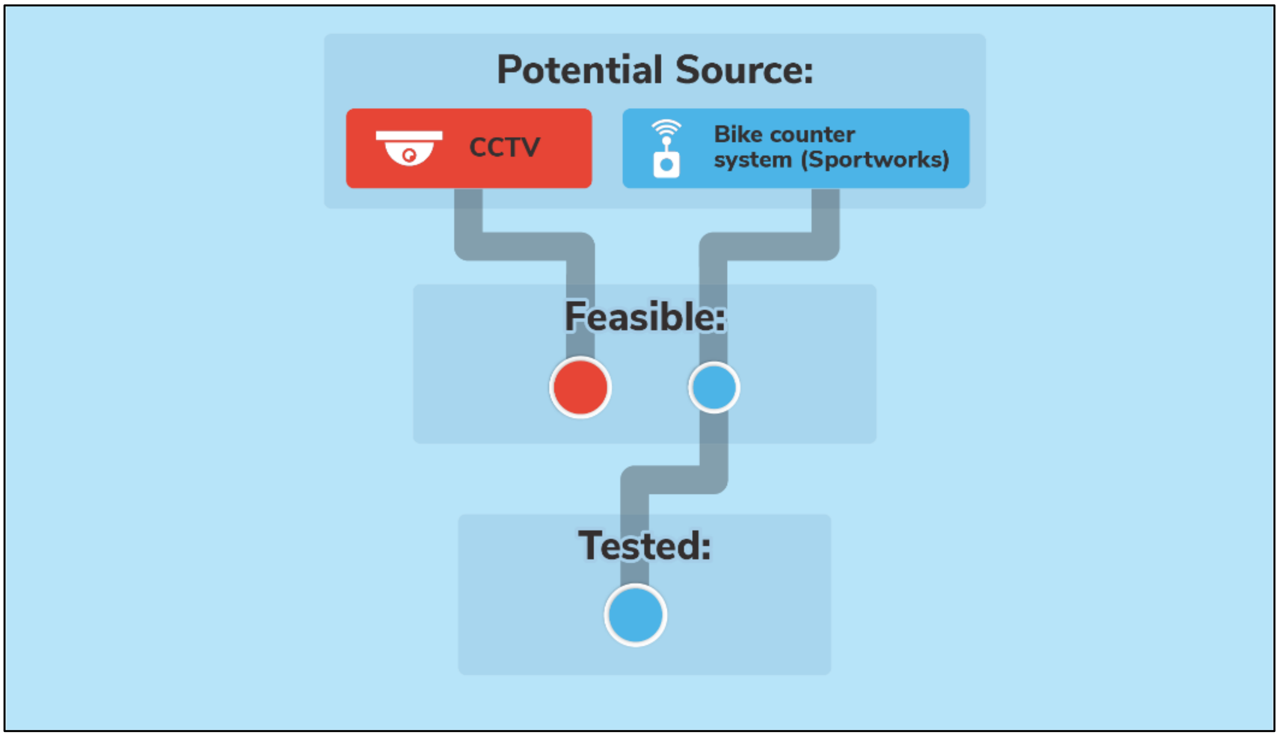
3.2 Vendor Selection

The project team interviewed multiple vendors that make products or provide services relevant to collecting and transmitting occupancy data. The project team selected vendors and technologies that could be constructed, installed, tested, and removed within the project duration, which would not affect the passenger experience.

Figure 3-1 and Figure 3-2 show which methods could or could not feasibly collect and transmit bike rack and priority seating area occupancy data, respectively. Both figures identify which methods were tested in Stage 1. The project team defined “feasibility” as the ability to install and measure the sensor’s feedback, despite any drawbacks.

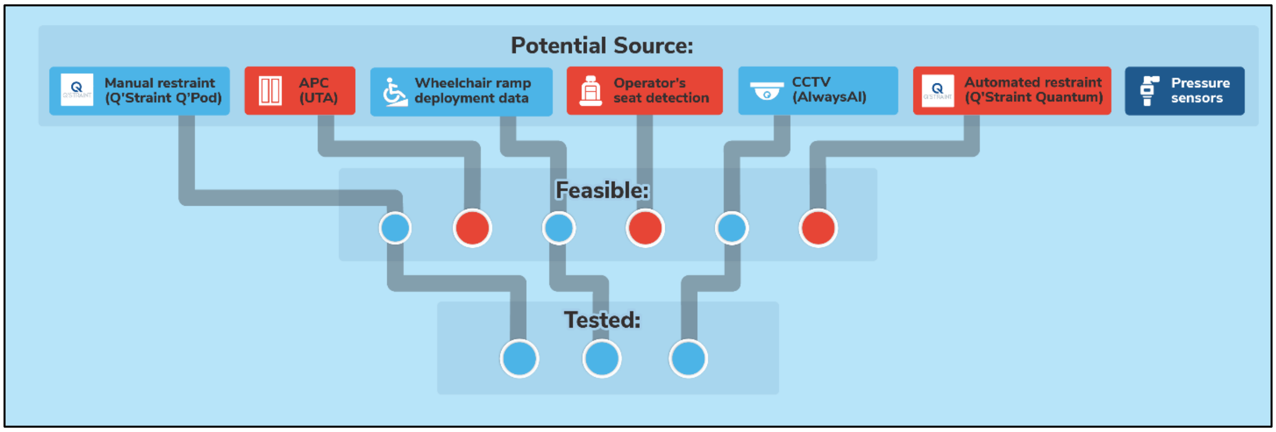
Table 3-1 and Table 3-2 list the methods explored for collecting bike rack and priority seating area occupancy data, respectively. Both tables include the quantity of sensors needed for each method, a description of each method, the concept behind the data, and the drawbacks of each method.

Figure 3-1. Technologies Explored for Collecting Bike Rack Occupancy Data



Source: WSP 2025

Figure 3-2.Technologies Explored for Collecting Priority Seating Area Occupancy Data



Source: WSP 2025

Table 3-1. Potential Methods for Collecting Bike Rack Occupancy Data

Method	Sensor Quantity Required	Description	Purpose	Usage Drawbacks
Bike Counter (SportWorks)	4	Magnetic reed switches for each of the three bike rack arms and one sensor for the folding rack deployment mechanism	Detects whether the bike rack is stowed (flipped up) or deployed (flipped down) and whether an individual bike rack slot is occupied (retention arm extended) or unoccupied	N/A
CCTV (alwaysAI)	1	Image recognition and analytics	The front-facing camera has the potential to detect bikes in the bike rack using computer vision	Amount of computing power necessary; challenges accessing real-time footage while the vehicle is in revenue service

Table 3-2. Potential Methods for Collecting Priority Seating Area Occupancy Data

Method	Sensor Quantity Required	Description	Purpose	Drawbacks
Q'POD (Q'Straint)	2	Magnetic reed switch inside the manual front tensioner of the wheelchair restraint; one unit on each side of the bus	Detects whether forward restraint is extended or in the stowed position	40 to 70 pounds of tension are required; front tensioner must be used to secure wheelchairs
Quantum (Q'Straint)	1	Semi-automatic wheelchair restraint	Detects whether the automated chair restraint is in the occupied position or in the ready-for-passenger position	Could cause motion sickness because it would require passengers to face the rear of the bus; no rear signage for passengers to see approaching stops
Wheelchair Ramp Deployment (Gillig)	1	Built-in wheelchair ramp analytics	Detects whether the wheelchair ramp has been deployed	There are other reasons to deploy the wheelchair ramp; each ramp deployment could be for multiple onboardings or alightings
Automatic Passenger Counter (APC) (Urban Transport Associates)	2	APC image recognition	Detects whether a wheeled device enters or exits and its general type (bike, wheelchair, or cart)	Accuracy concerns due to APC technology implementation
CCTV (alwaysAI)	1	Image recognition and analytics	Detects wheeled devices within the view of CCTV camera(s), their location in the bus, and general type (bike, wheelchair, or cart)	Privacy; computing power necessary; challenges accessing the footage while the vehicle is in revenue service
Driver Seat Pressure Sensor (Gillig)	1	Built-in vehicle seat pressure sensor	Detects occupancy of the driver's seat to determine if the driver is assisting a passenger with a wheeled device	Driver could vacate their seat for many reasons during service, not only to help a passenger with a wheeled device

Method	Sensor Quantity Required	Description	Purpose	Drawbacks
Sensor for seat Orientation (Generic Product)	2	Generic sensor; one for each of the priority seating benches	Detects if the priority seating area is in use by registering if it is in the folded or unfolded position	Can only tell if the bench is up or down, not if it is in use; must be used in conjunction with other methods
Pressure Sensor for Seat Occupancy (Generic Product)	6	Generic pressure sensor; one in each of the three seats on each priority seating bench	Detects if a person or object occupies a priority seat	Would require extensive seat modifications; on-board computing devices would not be able to accommodate six extra inputs for only seat monitoring

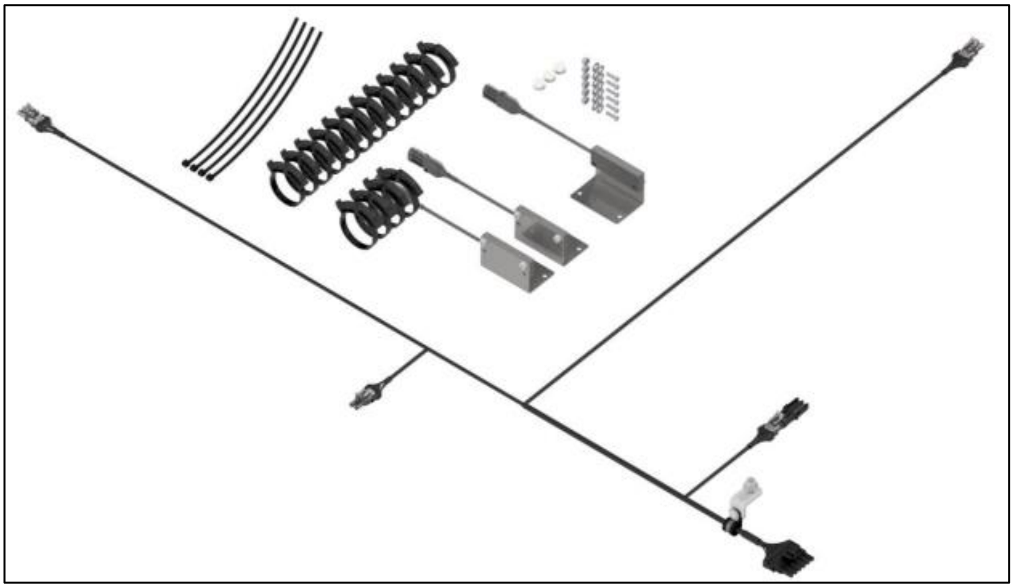
Ultimately, after extensive consultations with all vendors, Sportworks, Clever Devices, Q'Straint, and alwaysAI offered to pilot different configurations of appropriate technologies.

Among the options not selected was another product from Q'Straint called Quantum, which is an automated wheelchair restraint system. VTA opted not to pursue this method because it would require passengers to face the rear of the bus, where they would be unable to see when their destination stop was near. This method could also cause motion sickness from facing the opposite direction of travel.

3.2.1 Sportworks

Sportworks designs, manufactures, and distributes most of the commercial bike racks on transit agency vehicles across the nation, including those used on VTA buses. Specifically, the Sportworks Apex 3, three-position bike racks are already installed on many VTA buses. These racks have three slots for up to three bikes of any size and a bike counter kit (Figure 3-3) that consists of a magnetic reed switch on each retention arm and another reed switch on the rack itself to monitor deployment from an upright position.

Figure 3-3. Sportworks Bike Counter System



Source: Sportworks 2025

Sportworks also offered its Velolink system (Figure 3-4), which consists of a microcontroller, a processing unit, and a cellular modem. The microcontroller continually monitors the sensors of compatible Sportworks bike racks, determining when the bike rack is deployed and if any or all the bike slots are in use. The system forwards these signals through the cellular modem to Sportworks' servers, where the data can be accessed directly using their web interface or indirectly through an API.

Sportworks stated that Velolink could provide agencies with an alternative to on-board CAD/AVL integration for bike rack and priority seating occupancy monitoring by directly transmitting data to the cloud, independent of other technology on the bus. Sportworks would then add trips, stops, and routes by post-processing the occupancy data against the General Transit Feed Specification (GTFS) based on time and location.

When Sportworks originally joined the Project, they offered their new Velolink product specifically for bike rack monitoring. In the midst of bike rack monitoring, Sportworks quickly adapted and offered to integrate Velolink with the Q'Straint Q'POD tensioner, which is used for wheelchair occupancy monitoring, specifically for this Project.

Figure 3-4. Sportworks Product Ecosystem

Source: Sportworks 2025

3.2.2 Clever Devices

Clever Devices designs scalable and modular ITS to benefit transit system operators and the riding public across all modes of public transportation, including fixed-route, bus rapid transit, paratransit, and rail. Clever Devices' key solution is its CAD/AVL system, CleverCAD, which enables dispatchers to communicate directly with vehicles and manage routes by providing dispatchers and supervisors with a clear, real-time picture of the location and status of every in-service vehicle and the ability to quickly react to service disruptions in real time. VTA buses already have Clever Devices IVN hardware installed and running CleverWare software (Figure 3-5), which functions as the vehicle logic unit and connects to and controls almost all systems on the bus.

Figure 3-5. Clever Devices IVN 5

Source: Clever Devices 2025

3.2.3 Q'STRAINT

Q'Straint provides wheelchair securement and safety products for transit buses, school buses, and private vehicles.

VTA buses already have two Q'POD wheelchair securement stations installed. Each Q'POD station consists of two automatically retracting belts with hooks and a manually tightened, lever-action, front tensioner belt with hook (Figure 3-6). Although VTA uses Q'Straint Q'PODs on its buses, a new version was developed since the initial installation.

The new Q'POD system is the same as the prior iteration, a three-point restraint system, but it now includes a magnetic reed sensor inside the front tensioner unit. When the tension threshold is reached at the front restraint, the system can send a message to any connected system via a binary high- or low-voltage signal to indicate that the Q'POD station is in use. Q'Straint provided the project team with two updated front tensioner units, which were installed and were a drop-in replacement for the existing units on Bus 3402.

Figure 3-6. Q’Straint Q’POD Tensioner

Source: Q’Straint 2025

3.2.4 alwaysAI

alwaysAI delivers enterprise-grade software to apply computer vision techniques across industries. Through this SMART grant, alwaysAI helped detect priority seat availability using existing CCTV footage. This computer vision application enhanced visibility into bus occupancy trends and gathered insight into the type of “wheels” occupying the priority seating area. The project team selected alwaysAI because of their relationship with VTA and their demonstrated ability to build industry-first applications. alwaysAI’s solution is integrated with VTA’s existing camera and network infrastructure and requires minimal additional hardware to scale. By implementing computer vision, this Project has established the foundation for future vision-based predictive capabilities on board transit vehicles.

alwaysAI’s product suite enables organizations to embed computer vision into their existing operations. Powered by their proprietary edgeIQ software, alwaysAI delivers software to implement and manage vision-based applications on the bus instead of at a central server location or directly from the buses themselves.

Section 3.6, *CCTV-Based Occupancy,* explores the insights from alwaysAI's proof-of-concept and an alternative open-source method for detecting priority seating area occupancy.

3.3 Performance Measures for Prototype

The performance measures that VTA proposed for this Project were informed by community outreach and may differ from those envisioned at the time of this Project's inception.

From a prototyping standpoint, the measures of success were clear. From a hardware perspective, the system will report the correct occupancy data in 99% of scenarios because of the low-voltage circuits and the use of magnetic reed switches, which have lifespans of billions of activations in both the Sportworks bike counter system and Q'Straint Q'POD.

As discussed further in Section 3.5.1, *Configurations*, all implementations of sensor-based, real-time occupancy data were collected by the same sensors before being transmitted to different software solutions. Therefore, the only difference between the systems was each vendor's ability to display, analyze, and summarize data in a user-friendly way. This variable is qualitative. For this reason, standardizing its measure of success is difficult; however, the project team determined that being unable to display real-time data or a functionally incomplete software was a failure. Stage 2 would explore a broader application of this technology and the project team would revisit the performance standards and their outcomes.

3.4 Benefits to Passengers and Alignment with Federal Goals

Per IIJA Public Law 117-58 Section 25005, this Project provides a new data stream for transit agency staff (and potentially passengers in future stages). Providing access to occupancy data for bike racks and priority seating areas would improve passengers' trip planning capabilities. With this data, passengers could decide whether to take a later bus on the route, switch to an alternate route, or switch to an alternate mode of transportation.

Stage 1 of the Project demonstrated improvements mentioned in IIJA, specifically:

"*Improv[ing] the safety and integration of transportation facilities and systems for pedestrians, bicyclists, and the broader traveling public*", and "*Connect[ing] or expand[ing] access for underserved or disadvantaged populations.*"

Access to occupancy data would allow wheelchair users or bicyclists who bring their "wheels" on board buses to make better-informed decisions about their transit journey. Even if passengers cannot board the bus they initially intended, this data would enable them to feel more in control and ultimately have a better passenger experience.

As discussed in Section 2.2, *Community Impact*, these new data streams could also help VTA better plan its service for its affected passengers.

Stage 2 would include defining how VTA can use this data and, based on its use, engage with peer agencies and technology partners to explore modifying the GTFS-RT specification.

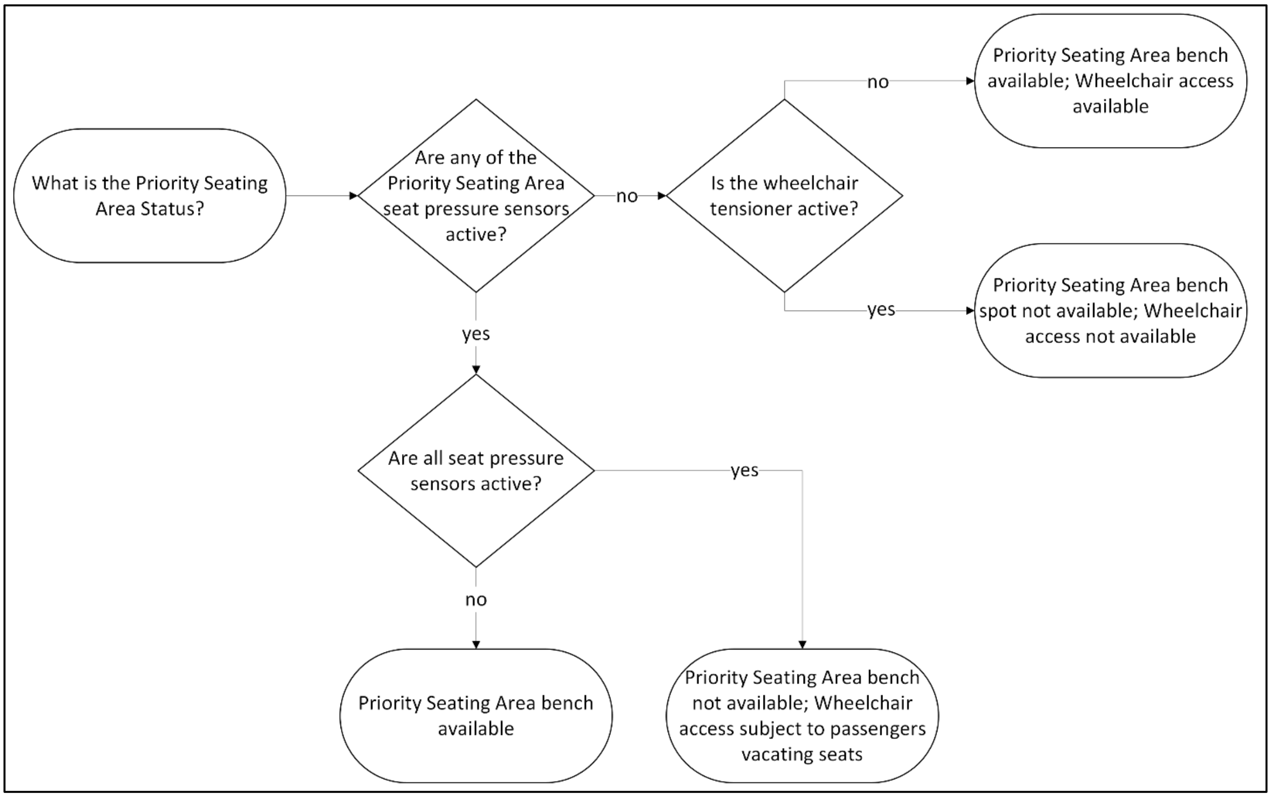
3.5 Sensor Implementation

Because bikes are the only objects allowed in the bike racks, and the racks can only be in occupied or non-occupied states, collecting and evaluating this data is straightforward. However, collecting occupancy data for VTA's priority seating areas is more complicated because the area is shared and can be occupied by ambulatory passengers, carts, strollers, personal belongings, or wheelchair users.

With this factor in mind, the project team created an occupancy flow chart for a priority seating area (Figure 3-7). The occupancy flowchart relies on using the binary outputs from generic seat pressure sensors in each of the three seats on the priority seating bench and the Q'POD front tensioner from Q'Straint.

Although not an explicit goal of the Project, using seat pressure sensors would make it possible to determine if the area was open for mobility devices and if space is available for ambulatory passengers to use the priority seating area bench seats.

Figure 3-7. Flowchart for Priority Seating Occupancy



Source: WSP 2025

From a hardware allocation perspective, the number of discrete inputs this configuration required—eight for just the priority seating areas or twelve including the bike rack—proved too many for either of the vendor's computing systems to handle.

For this reason, the project team decided on three configurations, with a maximum of six discrete inputs, using the Sportworks bike counter system (four sensors), and two Q'Straint Q'PODs, each with a single sensor. These configurations do not allow for differentiating between some of the scenarios described above, namely, only being able to tell if a

The project team decided on three configurations, with a maximum of six discrete inputs, using the Sportworks bike counter system with four sensors and two Q'Straint Q'PODs, each with a single sensor.

person using a wheelchair is in the priority seating areas.

3.5.1 Configurations

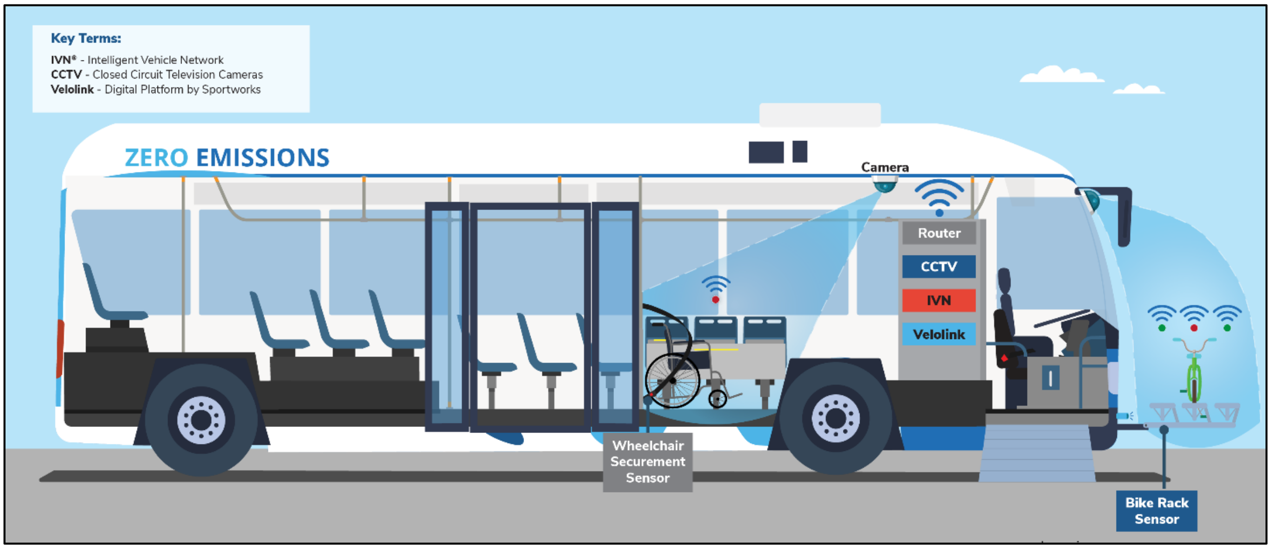
As described above in Section *3.2, Vendor Selection*, the technologies offered by Project Partners constitute three bus configurations of a system that would collect and transmit occupancy data for bike racks and priority seating areas.

Table 3-3 lists these three bus configurations, technologies, descriptions of the configurations, and descriptions of the testing locations. Figure 3-8 shows a high-level diagram of these systems.

Table 3-3. Descriptions of Configurations

Technology Name	Description of Configuration	Testing Location
Velolink	Sportworks bike counter system (bike rack occupancy detection), Q'Straint Q'POD (priority seating area occupancy detection), Sportworks Velolink (compute system).	Hardware-in-the-loop (HIL) test bench, on Bus 4403, and on Bus 3402
IVN	Sportworks bike counter system (bike rack occupancy detection), Q'Straint Q'POD (priority seating area occupancy), Clever Devices IVN (compute system).	Hardware-in-the-loop (HIL) test bench and Bus 3402
alwaysAI	CCTV (priority seating area occupancy detection),computer vision server (compute system)	Bus 4403

Figure 3-8. High-level Overview of the Occupancy Systems and Their Locations



Source: WSP 2025

For the Velolink and IVN configurations, Sportworks (Velolink) and Clever Devices (IVN) agreed to use sensor-based deployments. Their computing systems used physical sensors on the bike racks provided by Sportworks and in the Q'POD front tensioner provided by Q'Straint to detect whether bikes or wheelchairs are present.

The Velolink and IVN configurations do not differ in data availability because both use the same sensors. However, the configurations differ in how they record, deliver, and display data.

Whether the signals from the bike counter and wheelchair restraint are routed through the IVN or Velolink systems, both use Sportworks' bike counter system and two Q'Straint Q'PODs. The Sportworks bike counter system relies on low-voltage circuits controlled by four magnetic reed switches, one on each retention arm of each of the three bike slots, and another one that senses deployment of the bike rack from its upright position. The Q'Straint Q'POD uses a similar sensor inside each of the two front tensioner housings (one for each priority seating area) to determine if they are in use.

The project team did not conduct unit testing on each independent compute system but did conduct initial integration tests to confirm the sensors and wire harnesses were in working order.

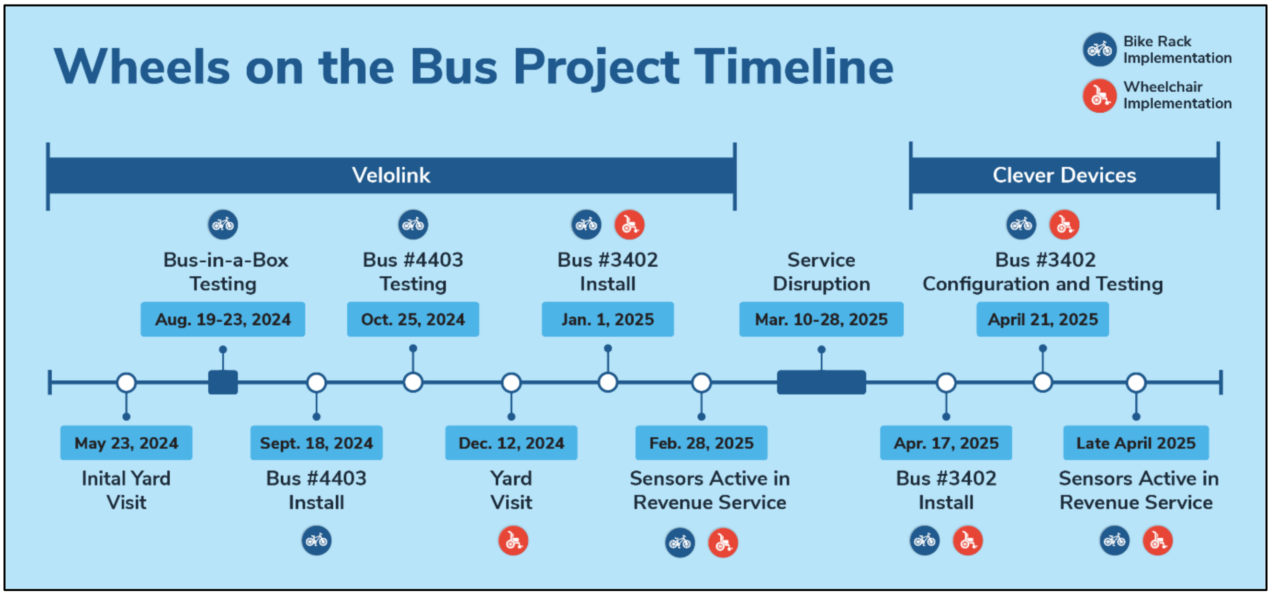
In contrast, the alwaysAI configuration uses the internal CCTV footage collected by VTA to determine whether an ambulatory passenger, a passenger in a wheelchair, or a bike are occupying the priority seating area or bike racks, respectively. After initially tagging the footage manually, alwaysAI trained a computer vision model to recognize passengers/bikes in the priority seating areas or bike racks and tag them automatically.

The remainder of this section focuses on the development, installation, and testing of the sensor-based configurations implemented by The project team on a hardware-in-the-loop (HIL) bench, Bus 4403, and Bus 3402.

3.5.2 Sensor Implementation Schedule

All sensor-related project activities were conducted over roughly one year, from May 2024 to April 2025. In March 2025, the Amalgamated Transit Union declared a service disruption against VTA. This disruption lasted from March 10 to March 28. During this time, there was no revenue service during which to collect data, and VTA's engineering technicians were unavailable for revenue service and project-related hardware retrofitting activities.

Figure 3-9. Timeline of Activities During the Project Period



Source: WSP 2025

3.5.3 Hardware-in-the-Loop

An Hardware-in-the-Loop (HIL) bench or "bus-in-a-box" is a test bench that replicates the physical hardware of an environment without having to work on a physical bus or withhold a vehicle from revenue service. Initial testing using VTA's HIL was completed with the help of Clever Devices' embedded engineers at the Guadalupe Yard VTA lab.

The VTA HIL was the ideal starting place for conducting tests because it allowed the project team to test system functionality and compatibility before retrofitting to a revenue service bus and impacting vehicle availability. Clever Devices, Q'Straint, and Sportworks all donated hardware, time, and expertise to verify that the sensors, wire harnesses, and computing units worked and ingested the data properly.

Each sensor contains a magnetic reed switch. When a magnetic field is applied to the sensor, the switch closes, acting as a pass-through for an electrical current. The "high-voltage" signal was 12 volts, and the "low-voltage" signal was 0 volts. An external power supply was used to supply the 12 volts required for the general-purpose inputs/outputs (GPIO) on the Velolink and IVN configurations.

Because the Velolink product was built to detect bikes via the Sportworks bike counter system, the system was plug-and-play. However, for the IVN configuration, the signals first need to be configured on a bus operator's Mobile Data Terminal[8].

Because the signals routed to the IVN had no identifying information other than the amount of voltage, the discrete inputs needed to be digitally labelled as bike or wheelchair to correctly distinguish between each signal before they were recorded in the vehicle state file. The vehicle state file is a Clever Devices' proprietary, tabular, timestamped, geostamped software that records all the activities that a bus has undertaken each day. The vehicle state file is saved in .csv file format.

For VTA's day-to-day CAD/AVL applications, the project team configured the IVN to upload the vehicle state file to an off-bus VTA server once per day when the vehicle returned to the depot for pull-in. Uploading the files once per day does not meet the project goal of providing real-time information to customers. However, Clever Devices did not have a proven way of providing real-time information for the desired occupancy data either through CleverCAD, their CAD/AVL software, or BusTime API, their real-time communication application programming interface.

> Stage 2 would require Clever Devices to develop a capability to provide real-time information for bike rack or priority seating area occupancy, which currently does not exist.

3.5.4 Bus 4403

After confirming that the sensors worked on the HIL and that the systems detected the changes in voltage from the bike counter and Q'POD circuits, the project team installed the sensors and compute system on a bus. Buses 4401, 4402, and 4403 comprise VTA's "innovation" line of vehicles. These buses are used to test new technology. These buses operate in revenue service but are limited to the routes that operate out of VTA's Cerone Depot, where the buses are stored. Of the three, Bus 4403 was selected for this Project.

[8] Each bus contains a Mobile Data Terminal (MDT) that operators use to communicate with Operations Command Center. It is part of Clever Devices CAD/AVL system and includes a keypad configured with custom codes.

Several years ago, the bike rack on Bus 4403 was installed as part of a different project that upgraded most of VTA's bus fleet to Sportsworks' three-position bike racks. VTA procured the bike racks with the rack occupancy sensors installed, but had not yet connected them to a data collection system.

In the fall of 2024, the project team experienced contractual issues with Clever Devices and could not proceed with any work with Clever Devices until the issues were resolved. The issue with Clever Devices resulted in a period when Sportworks became the primary partner on the Project. At this time, Sportworks, who originally committed to using Velolink only for collecting bike rack occupancy data, began developing a system for detecting wheelchair restraint occupancy, which the project team would test later on in the pilot.

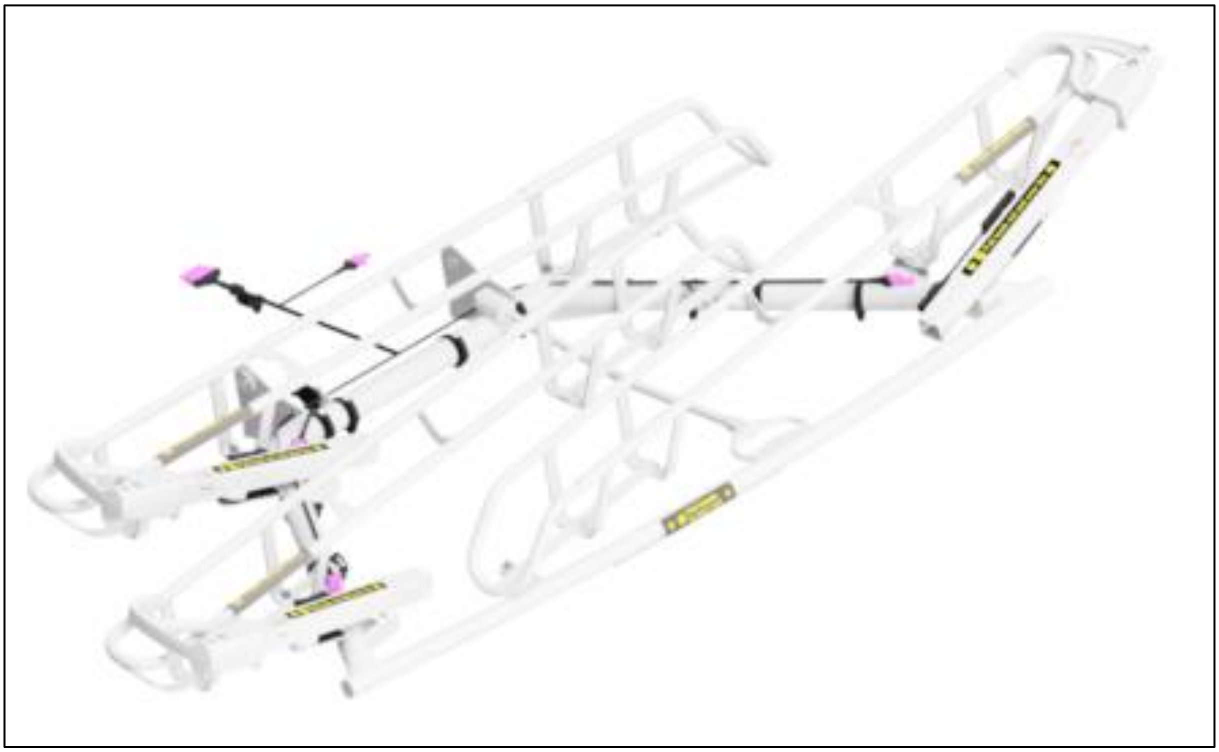
Ultimately, for Bus 4403, only the bike rack sensing was activated. Sportworks provided a preproduction unit of their new Velolink solution (Figure 3-10) for installation and testing.

Figure 3-10. Preproduction Velolink Unit Installed on VTA Bus 4403

Source: WSP 2024

The project team assessed whether the wires and sensors on the bike rack were still operational and found that the bike counter harness's primary connector, a six-pin Weather Pack connector, was left uncapped. As a result, the primary harness was rendered nonfunctional (Figure 3-11). Weather Pack connectors are sealed from water and dust via a rubber gasket when connected; therefore, the failure was likely caused by exposure to the elements after it was originally installed. The sensor breakouts were still functional; thus, only the primary harness was replaced.

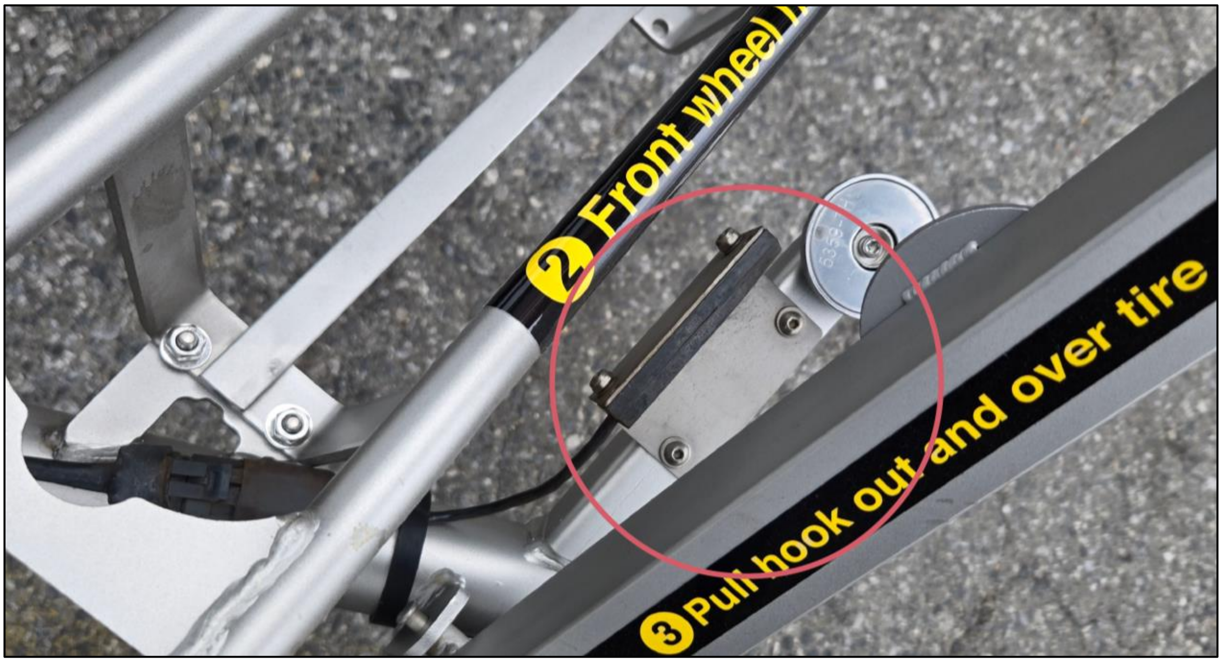
Figure 3-11.Sportworks Apex 3 Bike Rack Equipped with a Bike Counter System



Source: Sportworks 2025

Additionally, the project team noticed that the magnets attached to the retention arms of the bike rack, which open and close the magnetic reed switches, were missing (Figure 3-12). The Apex 3 bike rack design uses magnets attached to the metal housing of the arms using adhesive. Over time, the adhesive had become less effective because of exposure to adverse conditions, and the magnets fell off.

Figure 3-12. Missing Magnet on Bike Rack Retention Arm



Source: WSP 2024

The project team inspected other buses and found that although each vehicle was equipped with a Sportworks bike rack, most were either missing the magnets to activate the magnetic reed switches or missing the entire bike counter system itself, contrary to VTA's expectations. Although this discovery did not have any bearing on the Project's prototyping activities, the project team was surprised to learn that expected pieces of the racks were missing. This discovery may have a negative effect on the benefit-cost analysis (BCA) for implementing such a system fleet-wide.

> Although all buses are equipped with bike racks, many were missing the magnets that activate the sensors on the bike counter system. This issue highlights a need to develop maintenance and asset management plans to scale technology.

Upon notification that the magnets had fallen off the racks, Sportworks began internal testing to identify the cause and develop a solution. As of the conclusion of Stage 1, Sportsworks had identified the most probable cause and redesigned the magnet placement and other aspects of the bike rack to address the issue. The missing magnets on the Bus 4403 were replaced before the project team began testing.

For more information about the missing magnets, see Section 5, *Project-wide Challenges and Lessons Learned*.

After the initial continuity testing and replacing nonfunctional pieces of the harness, the harness was returned to normal operating condition. The project team installed the pre-production Velolink module, managed the wire harnesses to reduce any tension on the wires when folding the rack from its upright position to its deployed position, and installed a Deutsch DT06 two-pin connector for integrating with on-board vehicle power.

The project team developed 17 system-level test cases to test the bike counter's ability to detect and record adding or removing bikes and provide the corresponding correct response on the Velolink dashboard.

Initially, problems communicating occupancy data through the cellular network resulted in delays of up to two minutes from test case action to occupancy status change on the Velolink dashboard. This delay appeared to be caused by server communication errors over the cellular network (Figure 3-13). Sportworks was informed of these errors and is working to reduce delays to less than ten seconds on average.

Figure 3-13. Example of Pre-Production Velolink Server Communication Errors

Device Errors: Past 5 Days

Device errors are buffered on the device and may or may not be real-time

5 Days | 10 Days | 30 Days

Timestamp	Level	Message
Fri Oct 25 2024	ERROR	Failed to send data to the server, buffering data...
Fri Oct 25 2024	ERROR	Failed to send data, buffering...
Fri Oct 25 2024	ERROR	Failed to send data to the server, buffering data...
Fri Oct 25 2024	ERROR	Failed to send data, buffering...
Fri Oct 25 2024	ERROR	Failed to send data to the server, buffering data...

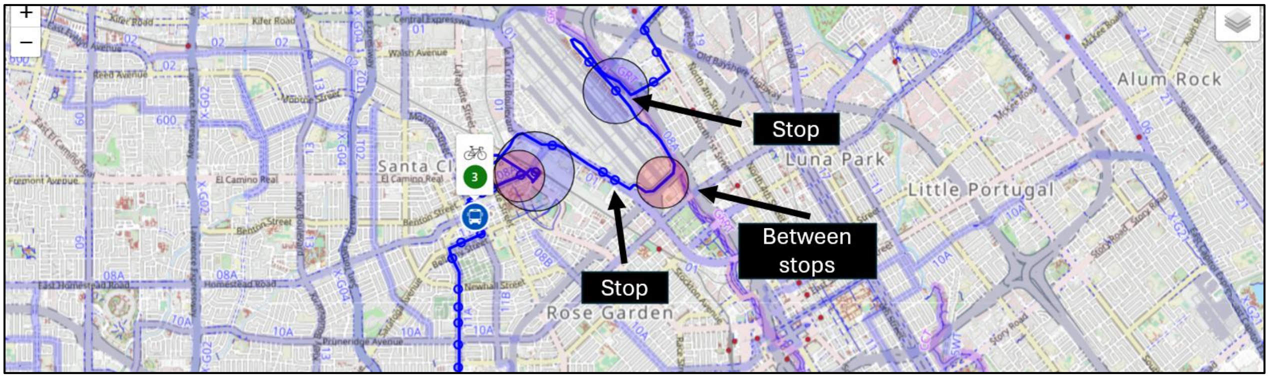
Source: Sportworks 2024

While experimenting with an unrelated test case, the project team found that the Velolink dashboard did not report occupancy correctly on one of the rack slots when the retention arm of the rack was moved up and down rapidly in proximity to the magnetic reed sensor. The project team hypothesized that the magnetic reed switch had somehow gotten stuck in the open position (in use) or that the rapid switching, which would not occur under normal circumstances, combined with the server latency the project team was experiencing, made the software misinterpret the signal. Resetting each arm for several seconds fixed the issue, and it could not be replicated.

> The Project Team developed 17 system-level test cases to test the bike counter's ability to detect changes in bike rack occupancy. All 17 tests ultimately passed but revealed the need for post-processing logic on unexpected occupancy changes *between* stops.

All 17 test cases passed; however, two of the test cases were originally marked as failures before Sportworks clarified that the racks were performing as intended. The tests in question involved virtually assigning the test vehicle bike rack to another VTA bus that was actively traveling in revenue service and testing a change in bike rack occupancy between stops. The project team assumed that if rack occupancy changed between stops, Velolink would report that change as having occurred at the closest stop and attribute the discrepancy to latency or global positioning system (GPS) inaccuracy. However, Velolink reports occupancy state changes exactly when and where they occur, even if it is between stops (Figure 3-14). Sportworks commented that this is working as intended and has a potential use to identify and combat bike theft while the bus is temporarily stopped, such as at a red light.

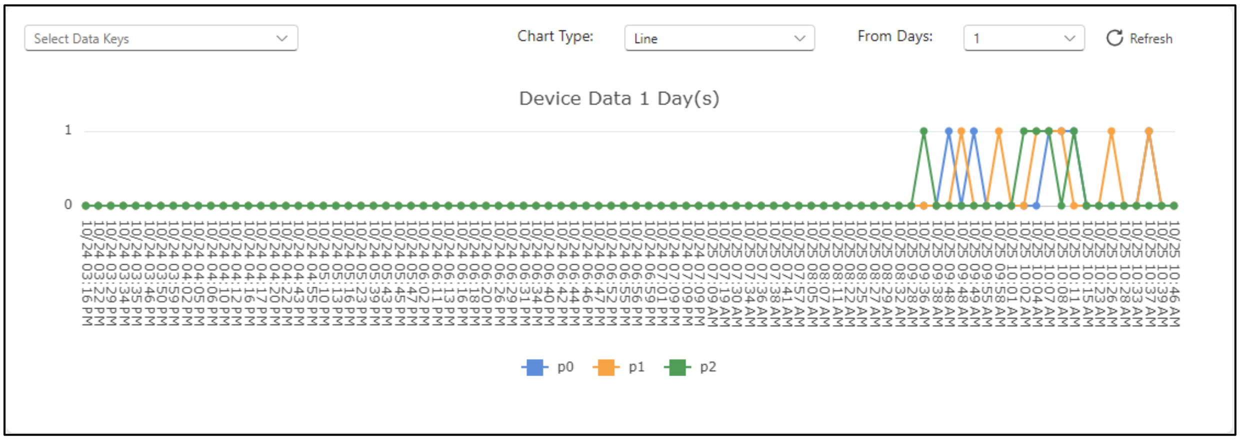
Figure 3-14. Example of A Bike Alighting Between Stops



Source: Sportworks 2024

Figure 3-15 shows an example of the project team's early testing. The x-axis represents stop times, and each line represents the addition or removal of a bike. The colors represent one of the three bike rack slots. VTA could use this data to identify whether passengers tend to use one slot more than the others, in which case could indicate if a slot requires more frequent maintenance.

Figure 3-15. Early Version of the Velolink Dashboard Recording Bike Rack Occupancy



Source: Sportworks 2024

3.5.5 Bus 3402

For the next phase of testing, VTA gave the project team access to Bus 3402, which was not part of the original series of buses allotted for this Project. Bus 3402 is a 2023 Gillig 40-foot eGen Flex. Access to this bus also meant access to a newer model of the Q'POD wheelchair restraining system. This allowed the project team to simply install the Q'POD tensioner provided by Q'Straint instead of retrofitting it onto an older model of the restraining system.

Additionally, Bus 3402 has a slightly modified seat configuration compared to older models; it has an individually foldable jump seat to the left of the priority seating bench (Figure 3-16). The project team hypothesized that this configuration would allow passengers with wheelchairs to still use the Q'POD even if the jump-seat area is occupied by ambulatory passengers or personal belongings. This flexibility, in turn, would help improve the quality of data collected for the Project.

Figure 3-16. Modern Priority Seating Area on Bus 3402

Source: WSP 2024

At this point in testing, contractual issues with Clever Devices were resolved, and they rejoined the Project. With the help of both Sportsworks and Clever Devices, the project team developed a plan to use both occupancy systems, Velolink and IVN, on the same bus. This system would collect both bike rack and priority seating area occupancy on a single bus in revenue service.

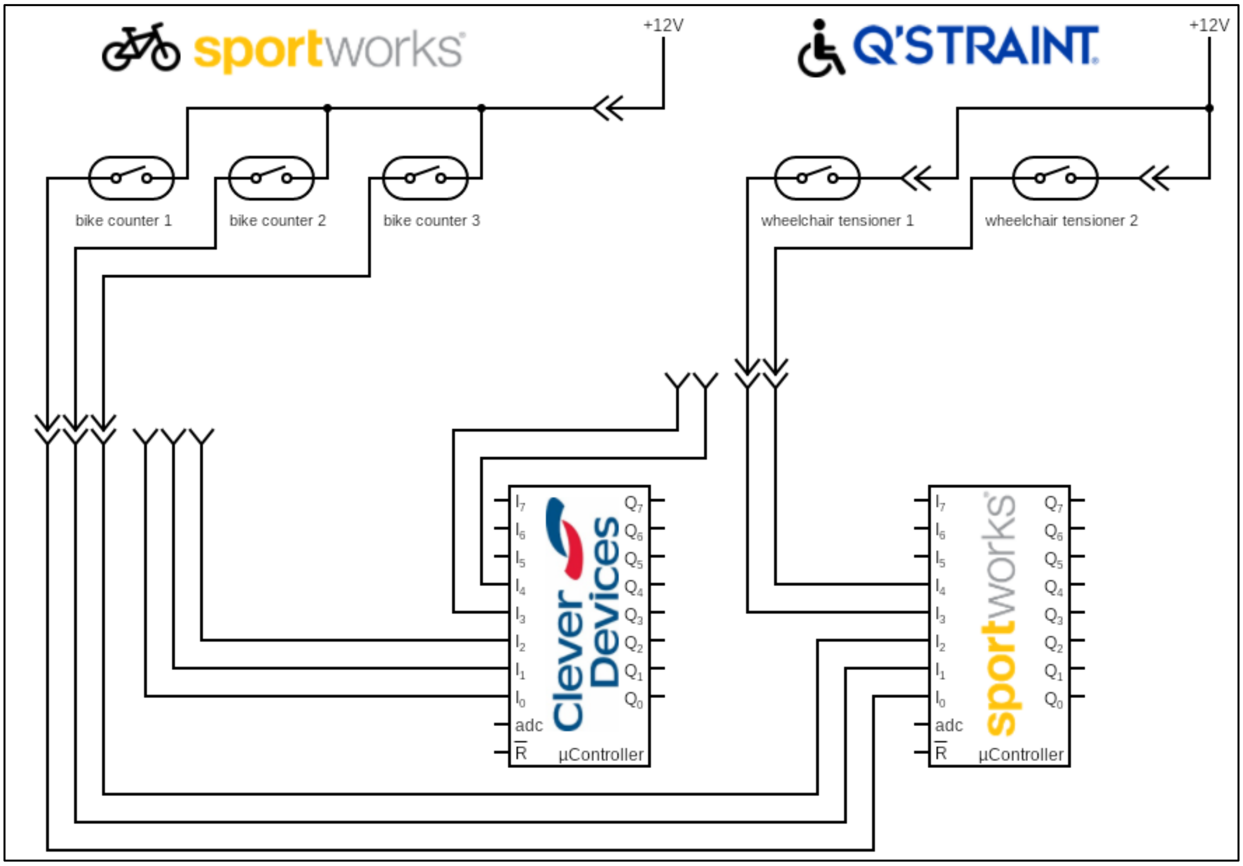
> With the help of both vendors, the Project Team developed a plan to use both occupancy systems, Velolink and IVN, on the same bus. This system would collect both bike rack and priority seating area occupancy on a single bus in revenue service.

To avoid introducing any potential variables caused by issues with a new bike counter system, sensors, or wire harness, the entire bike rack and bike counter system from Bus 4403 was transferred to Bus 3402. The on-bus installation consisted of two separate systems — Velolink and Clever Devices IVN— independently connected to the bike counter harness and the two wheelchair tensioners on board the bus.

The Velolink system operated much as it did during the dedicated bike counter testing, but it had two additional inputs from the Q'POD wheelchair tensioners. Similarly, the IVN system used the same six discrete inputs, but they were routed to the on-board IVN unit.

The Velolink and Clever Devices systems could not be operated simultaneously, though switching between them, as shown in Figure 3-17 (bike rack deployment switch not pictured), was designed to be simple.

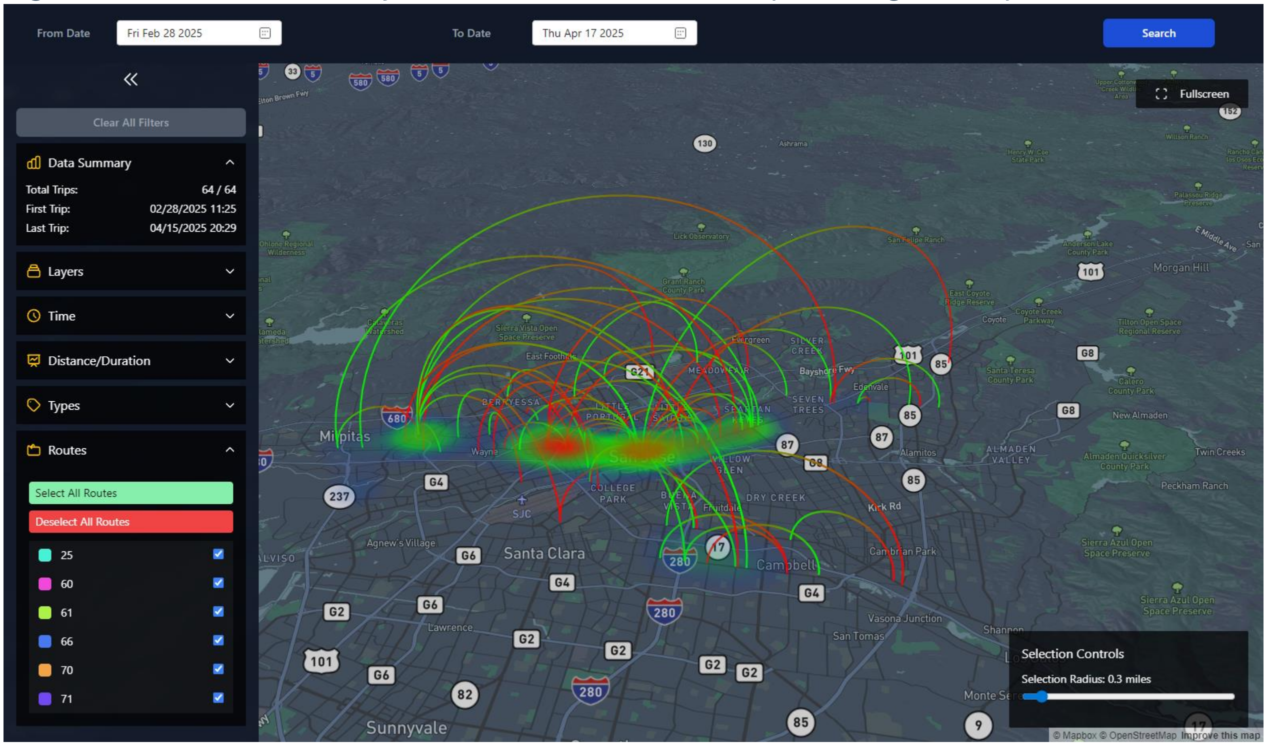
Figure 3-17. Wiring Diagram for the Sportworks Velolink and Clever Devices IVN



Source: WSP 2024

With the help of VTA's on-site engineering technicians, the systems were installed and wired without incident. The project team elected to let the Velolink module be connected first. During this install, Sportworks also upgraded VTA's preproduction unit to a production unit and unveiled new dashboard features, such as Journeys, and provided a much-appreciated graphical update. The Journeys Dashboard, as seen in Figure 3-18, shows color-coded arcs for origin-destination pairs, and usage heatmaps. Additionally, because Velolink could track origin-destination pairs, trips could be filtered by occupancy type, time of day, duration of time or distance, and route number.

Figure 3-18. Velolink Journeys Dashboard - Recorded Trips During the Project Period



Source: Sportworks 2025

Velolink was the primary system installed on Bus 3402 between February 28 and April 16, 2025. During that time, the system registered 64 bike trips over six routes (25, 60, 61, 66, 70, 71). There was a roughly even distribution throughout the day, with a slight peak between 10 AM and 3 PM, as shown in Table 3-4. This data collection period includes the service disruption between March 10 and March 28, 2025.

Table 3-4. Bike Trips by Time of Day

Time of Day	Number of Bike Trips
5 AM to10 AM	13
10 AM to3 PM	23
3 PM to8 PM	16
8 PM to5 AM	12
Total	64

A total of 32 trips (half of the total trips over the period) traveled less than 2.5 miles, with 21 trips occurring between 10 AM and 8 PM. Nine of these short trips were centered around the First, Second, and Third street VTA stops in downtown San José between 10 AM and 8 PM. These stations represent the closest stops to San José State University on their respective routes in the direction of travel. For this reason, the project team suspects that these trips were likely taken by college students going to and from classes at San José State University.

The other 32 trips were equal to or longer than 2.5 miles, with most origins and destinations in Campbell, South San José, and Milpitas. The time distribution of trips was even throughout the day. Eight of these long trips began or ended at the Montague Expressway & Great Mall Parkway VTA stop in Milpitas. The project team concluded that most of the trips were likely taken by people commuting to work or other activities because the distances were longer, and the trips occurred evenly throughout the day, including during the time blocks outside San José State University's usual hours. [9]

Velolink did not register any priority seating occupancies in revenue service between February 28 and April 16, 2025. The project team visited the VTA Cerone yard to verify that the sensors in the Q'POD wheelchair tensioner were working properly and found that they were. It is possible that Bus 3402 did not encounter any passengers who required the wheelchair tensioners, but this is highly unlikely because there were active wheelchair ramp deployments during the same period. More likely, the front tensioner was not used to secure passengers, or the tension applied to the tensioner via the lever was not enough to activate the sensor in the unit. In either case, this operational challenge will need to be overcome to collect accurate wheelchair occupancy data in the future.

Starting on April 17, 2025, the IVN was connected to the bike counter system and Q'POD wheelchair tensioners via the GPIO pins on the back of the IVN. As discussed in Section 3.4.3, *Hardware-in-the-Loop*, the same configuration steps needed to be taken on Bus 3402's MDT before the system could recognize the inputs. For the system to recognize each input for its classification and location on the bus, each input needed to be digitally assigned to each bike rack slot and wheelchair tensioner. The bus operator's MDT, which runs Clever Devices' software, shows icons with the real-time status of the bike rack and

---

[9] Although drawing conclusions from the data collected is not necessarily a part of this Project's prototyping scope, these examples show the surface-level assumptions that could be made when this data is made available to an agency.

Q'POD tensioners. These status icons allowed the project team to verify that the sensors were transferring information from the sensors, through the IVN, and into the MDT.

Unfortunately, a few days after installing and configuring the IVN system, Clever Devices informed the project team that although the MDT was reporting the correct status, the values were not recorded into the vehicle state file. In other words, when the state file was uploaded to VTA's server at the end of each day, it did not contain data about the occupancy throughout the day's revenue service. Clever Devices informed the project team that the occupancy data fields in the vehicle state file were not yet available in the current CleverWare software version; however, this data would be implemented in the June 2025 release.

Clever Devices offered to update Bus 3402's IVN system to a new pre-production software build that included the occupancy data fields. However, VTA was not willing to accept the risk that comes with putting preproduction software on a bus used in daily revenue service, and so declined the offer. Additionally, because of the approaching project deadline, the project team could not wait for the June software version to be officially released. Because collecting occupancy data was not possible with the system as configured, the project team decided to end implementation of the IVN system.

3.5.6 Summary of Sensor Implementation

Between April 2024 and May 2025, the project team embarked on a comprehensive prototyping initiative that identified and tested several sensor-based applications across a range of platforms.

The project team's initial findings showed that applying a sensor-based occupancy system that could distinguish between all priority seating scenarios[10] would require an overwhelming number of sensors and retrofitting to a normal bus. No off-the-shelf system currently exists that can accommodate these requirements. As a result, the project team refocused on the problem statement and began searching for systems that could specifically collect bike rack and wheelchair occupancy data.

The two systems that showed the most promise were Sportworks Velolink and Clever Devices IVN. The project team tested the abilities of both systems to collect data across

[10] "All priority seating scenarios" refers to the full range of ways the shared priority seating area may be used or occupied (by people using wheelchairs, by ambulatory passengers, or by strollers, carts, or personal belongings) each requiring distinct detection methods. This concept is first introduced in Section *0, Collecting Priority Seating Area Occupancy Data*.

three different platforms (HIL/lab, Bus 4403, and Bus 3402). Although each system used the same sensor suite and had access to the same data, the project team had vastly different experiences using each system.

The Sportworks Velolink system was plug-and-play; the sensors, compute system, and software dashboard were all developed to work in tandem. Although development is still ongoing, the Sportworks Velolink API, which would be used to provide occupancy data to an outside service such as Transit App, is not functional yet.

Clever Devices IVN was adapted to work with the same sensors, but it failed to deliver real-time, or even historical, occupancy data. However, Clever Devices showed that their system can ingest the data from the same sensors and show correct occupancy on the bus operator's MDT.

The product space for detecting and reporting real-time occupancy of "wheels" is growing in the transit industry, but it is still in its infancy. Although the project team found some commercially available sensing options for bike racks and priority seating areas, accounting for all possible occupancy scenarios and reporting on that data was a different matter entirely.

The project team suggests further investigating seat pressure sensors and how they can be integrated into priority seating areas along with other off-the-shelf sensors to piece together a complete occupancy picture. Additionally, the project team identified several technologies that held promise; however, because of feasibility or implementation issues, these technologies were not tested during this Project. These should also be explored further.

3.6 CCTV-Based Occupancy

This section discusses computer vision technology, an alternative to the physical sensor-based occupancy detection discussed in Section 3.5, *Sensor Implementation*.

When examining different technologies, the project team considered the scalability of cost, staff effort, and flexibility.

One promising technology is the Closed-Circuit Television (CCTV) cameras, which are already outfitted on all VTA buses. As Artificial Intelligence (AI) algorithms continue to improve, using computer vision technology represents a promising mechanism to track priority seat area occupancy.

alwaysAI describes computer vision as “a cutting-edge field of AI that equips machines with the ability to ‘see’ and analyze visual data, much like humans do. [The technology] uses machine learning and neural networks to train computers to identify and interpret objects [for example, wheelchairs, strollers, and bikes] in the physical world.”

Although some open-source models can recognize humans, none can detect wheelchairs or other “wheels”. This Project successfully demonstrated that CCTV footage can be trained to detect the presence of an “object” in the priority seating area. [11]

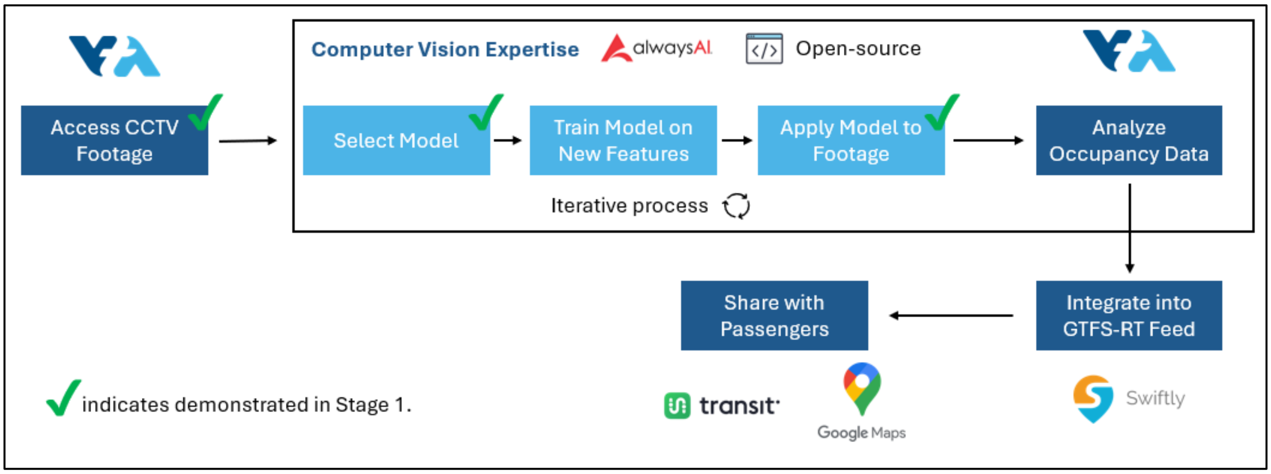
This Project demonstrated that CCTV footage can be used to detect when a passenger occupies the priority seating area using historical footage.

CCTV-based occupancy detection is promising. It could advance computer vision technology, it offers greater precision for detecting passengers using different types of “wheels,” it offers fleet-wide cost efficiencies, and developing relative software could be quick.

This existing model does not yet distinguish whether that “object” is a passenger bringing a particular type of “wheel” on board or sitting in the priority seat area. Figure 3-19 is a simplified graphic that shows the process of detecting priority seating area occupancy using CCTV footage.

[11] Object detection is a computer vision task focused on identifying and locating instances of objects within images. Object detection uses bounding boxes to classify objects within a particular area of the image (for example. around priority seating areas).

Figure 3-19. Using CCTV Footage to Detect Priority Seating Area Occupancy



Source: WSP

Note: Company logos represent VTA's technology providers; however, they are not explicitly recommended through this Project. Outputs of the computer vision model could be analyzed either by VTA or the computer vision partner.

The project team explored the following two methods for using CCTV footage to detect priority seating area occupancy:

1. **Vendor-led:** Through a partnership with alwaysAI, which delivers enterprise-grade software using computer vision
2. **Agency-led:** Through an open-source methodology aimed at giving agencies that have in-house software development capabilities full control over the modeling process

For more information about the advantages of these two approaches, see Section 3.6.3, *Comparison of A Vendor-Led Partnership Versus an Open-Source* (Agency-led) Method. The project team demonstrated the process that agencies can use to extract relevant footage from CCTV systems, followed by alwaysAI's ability to detect priority seating area occupancy using existing computer vision models. Stage 1 focused on footage retrieval and collaboration with alwaysAI, while Stage 2 will be an opportunity to further pilot the open-source methodology. This approach is detailed in Section 0,

.

The following sections describe the benefits of using CCTV footage for detecting priority seating occupancy, the process for accessing data through a vendor-led method versus an agency-led method, challenges, and next steps.

3.6.1 Benefits of Using CCTV Footage for Detecting Occupancy

There are several unique benefits of using CCTV footage instead of physical sensors for detecting priority seating occupancy, including the following:

- **Existing Cameras**: Cameras are installed across VTA's entire fleet; therefore, no additional capital costs or maintenance would be associated with this method. The existing cameras are placed at standard locations across the fleet, enabling rapid scaling of a refined model.[12]
- **Additional Precision:** Training an object detection model using CCTV footage could differentiate a wheelchair user from, for example, a pushcart, which is not possible through securement sensors alone.
- **Flexibility of New Technologies**: The rate of change in AI increases the need for information technology teams to thoughtfully invest in new hardware that will be relevant for the life of a bus. Using established camera technologies with constantly improving AI algorithms would help future-proof VTA, whereas physical sensors may experience technology obsolescence.
- **Multiple Use Cases**: Agencies can use computer vision's automated object detection capabilities for a variety of applications beyond detecting priority seat occupancy. Such technology could help validate bike rack occupancy using the external-facing camera, thereby leveraging one set of sensors (cameras) to track both sets of occupancies. Other use cases for computer vision could include bus lane enforcement, dwell time analysis, and collision avoidance. Investment in such technology could enable other applications in the future.

Additional software and on-bus hardware costs could arise, depending on whether data analysis is performed on the bus or in a central server room. For more information about these potential costs, see Section 4, *Anticipated At-scale Costs and* Benefits.

[12] Computer vision application may require additional computational hardware, "edge devices," to analyze footage in real time, discussed below and in Section 4, *Anticipated At-scale Costs and* Benefits.

3.6.2 Desired Functionality

Using CCTV to detect occupancy has two core functions: detecting multiple types of "wheels" on buses and recognizing each passenger's journey (origin-destination pair).

Currently, publicly available models can recognize humans, but they are not trained to detect the specific wheeled devices being analyzed for this Project (for example, wheelchairs, mobility scooters, strollers, and pushcarts).

Through computer vision analysis, CCTV footage will eventually be able to recognize and label each type of device with wheels. As a result, agencies could more effectively plan for the needs of passengers who bring "wheels" on board by understanding trip segments where there is insufficient space on board.

CCTV footage uniquely enables this advanced tracking, while obscuring any personally identifiable information from the data.[13] This information would enable transit agencies to consider demand for bike and wheelchair space when planning route headways and frequency.

Table 3-5 lists the information that computer vision technology could provide about occupancy data. The *occupancy_type* field would be available only through image recognition, not physical sensors described in the hardware-based discussion in Section 3.5*, Sensor Implementation*.

Stage 1 of the Project demonstrated the ability to use CCTV footage to detect priority seating area occupancy. Stage 2 would aim to prove whether differentiating between different types of "wheels" is possible by repeatedly providing a model with data that shows the defining characteristics of different types of "wheels." Through this process, the model might be able to recognize shared patterns in these objects and differentiate between them.

[13] The Project Team acknowledges that cybersecurity requires further investigation. For further discussion, see Section 3.6.6. Computer vision algorithms can obscure faces before transmitting footage and output data with a count of passengers, thereby anonymizing passengers' identities.

Table 3-5. Data CCTV Footage Can Provide Through Computer Vision Analysis

Data Element	Description
Date and Time	Directly available from CCTV footage
Location	Inferred based on footage timestamp, camera number, and CAD/AVL data
Operations (Route, Block, Trip)	Inferred, likely pulling from the real-time feed
Priority Seat 1—Occupied Status	A yes/no indicator based on whether the model detects an object in this area
Priority Seat 1—Occupancy Type	A future capability that could detect what is occupying this area, whether a passenger in a wheelchair, an ambulatory passenger a cart, stroller, or personal belongings. Capability would be validated in Stage 2
<Additional Priority Seats> — Occupied Status, Type	Extending the above logic from Priority Seat 1 based on the two or more priority seats available on a given bus configuration
Origin, Destination	By tracking the change in occupancy over time, post-processing analysis would recognize the stops at which passengers board and alight

3.6.3 Comparison of A Vendor-Led Partnership Versus an Open-Source (Agency-led) Method

The project team used alwaysAI's expertise and existing relationship with VTA to prototype the feasibility of computer vision. As a USDOT-funded project, this effort aimed to provide solutions that might appeal to a variety of agency types. As such, it also defined the approach for an agency-led, open-source method. Table 3-6 compares the key differences between an agency-led and vendor-led approach to computer vision. Table 3-6 covers factors such as staff support, cost, predictive accuracy of occupancy, and control.

Table 3-6. Comparison between Agency-led and Vendor-led Solutions

Dimension	**Agency-led Solution (VTA)**	**Vendor-led Solution (based on pilot with alwaysAI)**
Staff Support	Would require in-house staff with working knowledge of Python to make updates. Would also require server infrastructure (cloud or on-premises) to run computer vision model inference[1] in near real-time.	Minimal effort would be required from the agency. Data processing, analytics, and reporting could be handled entirely by the vendor.
Cost	Would generally be less expensive once a model is proven. Most costs would be incurred during the initial solution development.	Would typically be more expensive because of ongoing fees. Often follows a software-as-a-service pricing model.
Predictive Accuracy	Would have high accuracy using state-of-the-art, open-source computer vision models.	Would have high accuracy using either state-of-the-art open-source or proprietary computer vision models.
Cybersecurity	Would have lower risk because the data would stay within the agency's infrastructure and behind its firewall.	Could have higher risk because of data transmission, but risks could be mitigated through secure protocols.
Control over the Process	Would have high flexibility because agencies could modify model inputs and outputs directly, as needed.	Agencies would have limited control. Changes would require vendor involvement, often with additional development time and costs.
Support and Maintenance	Would requires dedicated agency staff for troubleshooting and updates.	Vendor would be responsible for ongoing support, updates, and maintenance.
Compliance and Legal Considerations	Would be easier to ensure internal compliance with local regulations and privacy laws.	Could require a detailed review of vendor practices to ensure compliance.

[1] "Inference" refers to using an existing, trained model to make predictions and not training the model itself. Most server machines can perform model inference efficiently. This analysis assumes that both approaches use a state-of-the-art, open-source computer vision model without further refinement.

The key value of an agency-led, open-source method is its ability to provide agencies with full control over the process and data security.

Because no computer vision model currently exists that can detect wheelchair users or bikes, existing models would need to be retrained based on actual footage and refined for the transit context. Many agencies may seek to partner with a vendor, such as alwaysAI, to lead the training process.

For more information about this agency-led, open-source method, see Section 0,

.

In both scenarios, agency-led (open source) and vendor-led, , agencies would need to find the right partners to guide the full process, from accessing footage to analyzing service planning trends, to providing information to passengers.

Additionally, although the computer vision model approach takes advantage of existing CCTV footage, eliminating the need to install new sensors, additional hardware may still be required, depending on how agencies choose to process the collected data. The two sides of such processing methods are server-based and on board the bus (edge) processing:

- **Server-based Processing**: To enable real-time analysis separate from the bus, a continuous communication between the bus and a central server is required to transmit CCTV footage. Currently, live feeds are transmitted only to the OCC during emergencies. In most cases, CCTV footage is stored locally and retrieved only when the vehicle returns to the depot.
- **On Board the Bus (Edge) Processing**: Alternatively, near real-time processing could be performed directly on the bus using edge processing performed by alwaysAI. However, this method would likely require new hardware because the existing systems on the buses may not have sufficient computing capacity or power efficiency to reliably support edge processing.

Both methods have trade-offs regarding data security, power needs, and transmission delay for passengers.

3.6.4 Access to CCTV Footage

Both the vendor-led and agency-led methods first required actual CCTV footage to assess the accuracy of using computer vision models. As a result, the project team's first step was to retrieve footage from VTA's Protective Services department. The project team faced a few challenges regarding footage availability, size, and security. Table 3-7 outlines these challenges and the corresponding solutions.

Table 3-7. Challenges to Accessing CCTV Footage[1]

Topic	Challenge	Mitigation Method	Next Steps (Stage 2)
Footage Availability	The VTA Protective Services department only retains footage from the last 30 days, while wheelchair ramp deployment records from Clever Devices are only available one day after each trip. Additionally, staff must physically retrieve footage from older vehicles.	Request the most recent ramp deployment data set and footage from within the last month. Avoid requesting footage from legacy vehicles to expedite access and minimize the time required from VTA.	Shadow the VTA Protective Services department to better understand the footage retrieval, slicing, and transmission process.
Request Size	VTA's Protective Services department has a backlog of requests to extract video clips for internal and external uses. They are resource-constrained, so footage requests must be efficient.	Request the fewest total minutes of footage and sets of recordings. The process to carefully select CCTV time frames based on expected use of "wheels" is outlined further below.	Develop a process in collaboration with VTA Protective Services department to access larger volumes of footage without impacting agency operations. For the continued pilot program, develop an automated pipeline to retrieve ramp deployment data from Clever Reports[2] and directly request access to CCTV footage.
File Download	Each 30-minute, two-gigabyte segment takes about 30 minutes to download, stressing limited network bandwidth and storage.	As mentioned above, footage requests must be for the fewest minutes with the highest number of expected boardings or alightings. More observed data improves how accurately the model detects occupancy.	
File Transfer	Given the sensitive nature of the CCTV footage, information cannot be digitally transferred from the VTA Protective Services department.	VTA staff must use physical storage drives to access footage and upload to a restricted project site.	Further refine this process when analyzing larger sample sizes. Outline how a real-time data transmission pipeline might function.

Topic	Challenge	Mitigation Method	Next Steps (Stage 2)
Cybersecurity	On-board footage is highly sensitive. VTA must closely control access, analysis, and retention.	All project information was retained within the project environment. Following the least privileges methodology, individuals only directly involved with the analysis had access during the project period.	Conduct a cybersecurity risk and mitigation analysis to protect this information during the pilot program and at-scale.

1 These challenges and solutions are listed in the present tense as ongoing challenges in Stage 2. However, they were each successfully resolved through the Stage 1 effort, with the corresponding next steps for Stage 2.

2 Clever Reports is the module within Clever Devices' IVN system that produces custom reports used across the agency. The wheelchair ramp deployment data is one example of a report available through this module. Other reports available through Clever Reports are Stop adherence, APC, and voice announcement reports.

As described in Table 3-7, the project team aimed to minimize file sizes and footage lengths maximizing the number of instances of passengers using wheelchairs boarding or alighting the buses. To accomplish this objective, the project team analyzed the ramp deployment data to identify the time periods during which more passengers were expected to board or alight using the ramp. The VTA Protective Services department also had footage from previous wheelchair-related incidents, which the project team could access more readily.

> The first key challenge in implementing computer vision is retrieving CCTV footage. To streamline footage requests, the project team developed an application to automatically identify time frames with high wheelchair movements. In the future, agencies will need to closely partner with safety and security teams to analyze footage according to agency protocols.

Figure 3-20 shows a sample dataset provided to the VTA Protective Services department to request footage with the highest volume of wheelchair movements as test data for the model.

The project team developed a Python script to group ramp deployment instances based on the frequency of deployments. It grouped deployments within a given time frame and a trip to minimize file size and recording length.

Figure 3-20. Sample Ramp Deployment Data for CCTV Footage

date	route	direction	vehicle	from_time	to_time	Ramp_deployments
9/25/2024	66 - N. MILPITAS - SANTA TERESA STN	SOUTH	3411	1446	1615	11
9/17/2024	66 - N. MILPITAS - SANTA TERESA STN	NORTH	3428	1100	1230	10
10/3/2024	66 - N. MILPITAS - SANTA TERESA STN	NORTH	2106	1302	1503	10
10/1/2024	66 - N. MILPITAS - SANTA TERESA STN	SOUTH	3431	800	830	9
9/28/2024	22 - PALO ALTO - EASTRIDGE	EAST	8347	923	1100	8
9/10/2024	61 - GOOD SAM - SIERRA & PIEDMONT	NORTH	3411	1645	1800	8
9/20/2024	23 - DE ANZA - STEVNS CRK - ALUM ROCK	WEST	138	1357	1522	8
9/12/2024	66 - N. MILPITAS - SANTA TERESA STN	SOUTH	3428	900	951	7
9/27/2024	25 - DE ANZA - VMC - ALUM ROCK	WEST	7450	1320	1409	7
9/14/2024	25 - DE ANZA - VMC - ALUM ROCK	WEST	145	1535	1655	7
9/25/2024	25 - DE ANZA - VMC - ALUM ROCK	EAST	7420	1000	1100	6
9/30/2024	68 - SAN JOSE DIRIDON - GILROY TC	SOUTH	153	1010	1100	6
9/19/2024	23 - DE ANZA - STEVNS CRK - ALUM ROCK	WEST	149	1310	1400	6
9/12/2024	66 - N. MILPITAS - SANTA TERESA STN	SOUTH	3435	600	645	6
9/10/2024	77 - MILPITAS BART - KING - EASTRIDGE	NORTH	3415	1312	1353	6
9/18/2024	23 - DE ANZA - STEVNS CRK - ALUM ROCK	WEST	165	1414	1508	6
10/1/2024	61 - GOOD SAM - SIERRA & PIEDMONT	NORTH	2037	847	920	6
10/4/2024	61 - GOOD SAM - SIERRA & PIEDMONT	SOUTH	3420	1438	1515	6
9/17/2024	73 - SJ - SENTER - SENTER/MONTEREY	SOUTH	7406	1010	1055	5

Source: WSP

3.6.5 Proof-of-Concept Findings

alwaysAI applied an existing computer vision model to the sample footage based on VTA's requirements. Figure 3-21 shows the findings from their sample video, including the following:

- Cameras can detect occupancy of priority seating areas.
- Priority seating areas are often occupied by passengers with pushcarts instead of wheelchair users. Passengers with pushcarts may need to be categorized separately in the dataset.
- When passengers cross through the camera's field of view, the algorithm could momentarily detect the priority seating area as being occupied. During Stage 2, the project team would refine detection parameters, such as how long a passenger remains in the priority seat and how often a status changes, to ensure that data is accurate and reliable.
- Lighting, seat configurations, and camera resolution quality can impact the accuracy of the model's occupancy prediction.

Figure 3-21. Preliminary Object Detection Showing a Pushcart in the Left Priority Seat

Source: alwaysAI 2024

These findings indicate promising results; the sample video accurately captured the exact moments passengers entered and exited the priority seating area.

3.6.6 Challenges Ahead and Considerations

VTA must address several technical and operational challenges to ensure both pilot and full-fleet scale success. One challenge is the availability and quality of training data. Although alwaysAI's initial attempt uses a small batch of clips, the full-scale model would be more accurate with a significantly larger and more diverse video dataset.

Limitations in available footage, such as scenes with high passenger density or weather-induced visibility issues, can affect model performance. Sun glare, camera quality, and inconsistent lighting conditions can introduce noise in the model. For instance, if an object passes through the field of vision for the priority seating area without persisting, it should not change the data feed; however, the first iteration of alwaysAI's real-time demonstration captured those instances as occupied.

During Stage 2, in partnership with an AI vendor, VTA would adjust detection parameters, such as how long a passenger remains in the priority seating area, the occupancy area's precise physical boundaries, and the lighting to increase the accuracy and reliability of the data collected.

During Stage 2, The project team would also refine the performance metrics. The central performance metrics are the acceptable percentages of false positives (that is, the space is not occupied, but the model shows the space as occupied) and false negatives (that is, a passenger is in the priority seating area, but the model shows the space as available).

CCTV footage is sensitive even if stored only temporarily. Any storage, processing, or transferring must meet VTA's standards for encryption. These standards guide how the footage is shared with modeling partners and how inference results are piped into operational systems. The project team would analyze cybersecurity and data governance in Stage 2.

With either approach, partnering with an AI vendor or using an agency-led, open-source method, the next objective is securely accessing CCTV footage in real time.

Currently, the OCC can access CCTV footage only in an emergency. The OCC can access a limited number of these feeds in real-time, typically not in high resolution, and can use the feeds to monitor only live instances. This information is available only on the bus's digital recorder during a run.

During Stage 2, the project team would explore how to access CCTV footage without physically changing to on-bus infrastructure. Table 3-7, above, lists improvements that the project team would make to the at-scale footage retrieval process during Stage 2. The following sections describe considerations across the vendor-led method, the agency-led, open-source method, and other applications.

alwaysAI

alwaysAI used CCTV footage to develop an initial proof of concept, showcasing how a computer vision model can automatically detect passengers in the priority seating area. The project team could improve this model in Stage 2 by identifying when there are multiple seating areas (for example, there is a pushcart right behind the left occupied region), training under different lighting conditions (for example, bright daylight versus at night with interior lights), and differentiating between types of occupancy.

To collect accurate and reliable data, the model must correctly identify these characteristics, particularly if passengers make travel decisions based on the data.

Vendor-led, Open-source Method

The project team would more closely analyze open-source modeling in Stage 2.

During Stage 2, the project team would use pre-trained models as a starting point to take advantage of existing state-of-the-art advancements in the computer vision industry, instead of developing a computer vision model from scratch. These models would function as the central element of the data processing pipeline, which would include preprocessing CCTV footage, identifying objects with the computer vision models, and post-processing results.

To improve accuracy, the system should include additional logic to handle common detection issues, such as missed detections caused by obstructions or sun glare. The pipeline should be able to analyze CCTV footage at a rate of at least one frame per second, making it possible to monitor priority seating areas and bike rack occupancy in near real time.

For reporting purposes, the pipeline outputs would be aggregated into 1-minute intervals and reported in near real time.

As described in Section 3.6.3, the vendor-led, open-source method offers several benefits. For example, agencies with large software development teams would have greater control over how occupancy data is processed and protected while reducing recurring analytics costs.

Below is an outline of a vendor-led, open-source computer vision method that the project team would explore during Stage 2.

Objective: Near real-time detection of priority seating area and bike rack occupancy on buses.

Data: VTA provided CCTV footage from bus priority seating areas and bike racks.

Output: A system that provides near real-time updates on the availability of priority seating and bus bike racks, updated every minute. These numbers can be further aggregated for agency reporting purposes or built into a real-time feed for public-facing applications.

Resource Needs: A server with a powerful graphics processing unit (GPU) and central processing unit to run computer vision models efficiently.

Analysis Steps:

1. Define and Pre-process Priority Seating and Bike Rack Areas

    - *Action*: Define the priority seating and bike rack areas in the video feed for each bus. Blur identifying information.

    - *Deliverable*: Clear identification of priority seating and bike rack areas in the video footage.

2. Develop Object Detection "Pipeline"[14]
    - *Actions*:
        - Select a lightweight, pre-trained object detection model to detect priority seating and bike rack occupancy.
        - Build a video processing pipeline capable of analyzing the CCTV footage at a minimum rate of 1 frame per second to monitor priority seating and bike rack occupancy.
    - *Deliverable*: A functional object detection pipeline that identifies seat and bike rack occupancy at a rate of 1 frame per second.

3. Frame-level Data Aggregation and Reporting
    - *Actions*:
        - Aggregate data from processed frames and update the status every minute.
        - Develop a logic to handle temporal inconsistencies in the frame data (for example, missed detections caused by occlusions).
        - Create a reporting system to provide near real-time updates on priority seating and bike rack occupancy every minute.
    - *Deliverable*: Near real-time reporting of priority seating area and bike rack occupancy, with updates every minute, or at least as frequently as the travel time between stops, based on aggregated frame data. Passengers currently see real-time bus locations, and passenger loads update every few seconds, which represent a similar data feed as priority seating areas and bike rack occupancy.

---

[14] A "pipeline" refers to a structured sequence of processing steps that produces usable outputs. These steps take input data (such as images) through stages such as preprocessing, model inference (object detection), and postprocessing to detect occupancy of wheelchairs onboard a bus. Pipelines are designed to ensure that each component works together to deliver accurate and repeatable results.

Once the project team determines that the model is collecting reliable and accurate data, the next step would be integrating the data feed into the real-time feed from Swiftly, VTA's software partner that provides passengers and operations with real-time arrivals and disruption information.

Bike rack occupancy data streams from Sportworks would coexist with priority seating area occupancy data in the real-time feed. For information about the process for showing this occupancy data on Transit App, Google Maps, and all other third-party consumer applications, see Section 6.1.3, *Real-time Occupancy for Passengers*.

Other Applications

VTA can use this same computer vision technology for multiple applications, including monitoring bike rack occupancy. By defining additional detection zones around bike racks, the CCTV footage could detect slot-level occupancy and turnover. This approach would eliminate the need for separate rack sensors and make it easier to integrate real-time updates of both priority seating areas and bike slots via trip-planning apps. During Stage 2, the project team would compare the relative costs and complexity of physical solutions and camera-based technologies.

3.7 Reporting Capabilities

After collecting priority seating area and bike rack occupancy data—through physical sensors or computer vision technology—the project team can generate insights to guide decision-making and improve service planning.

This section presents visualizations designed to help VTA's Service Planning department identify strategies to reduce denied boardings for wheelchair users or passengers with bikes.

These new data streams on bike rack and priority seating occupancy allow the project team to analyze data trends across the following dimensions:

A. Operational (for example, scheduled block, trip, and route)
B. Geographic (for example, stop location, origin, destination)
C. Temporal (for example, time of day, day of week, and month)

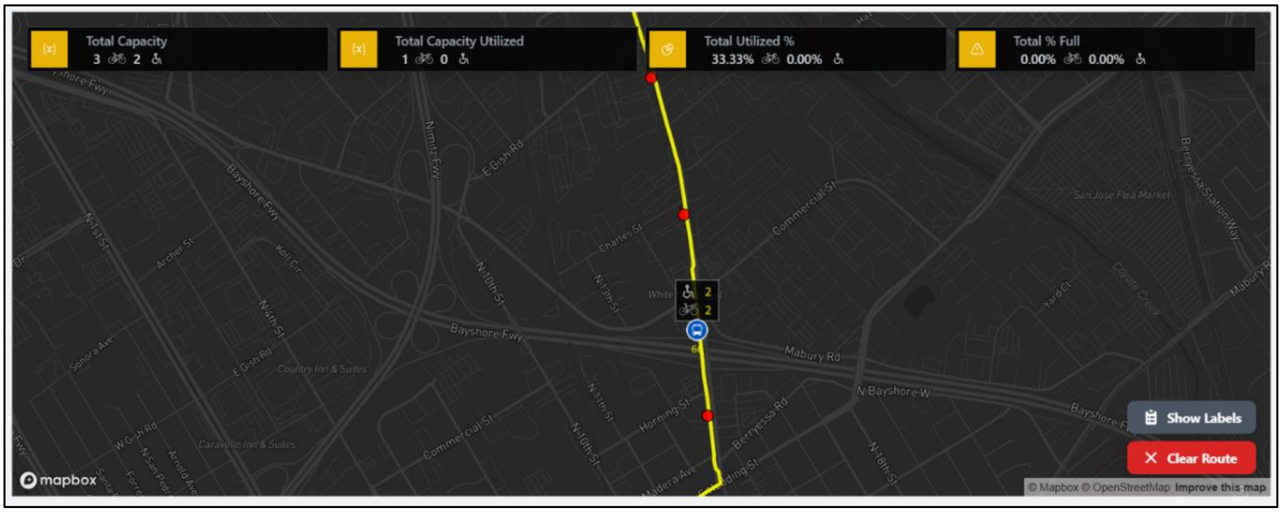
Section 3.7.1 explores the functionality and impact of Sportworks' Velolink web dashboard. Although the dashboard was initially designed to monitor only bike occupancy, the dashboard evolved over the course of this Project to include wheelchair sensor data.

3.7.1 Bike Rack Dashboard (Velolink)

Sportworks has developed a web dashboard that shows both real-time and historical trends in bike rack occupancy. The dashboard provides the total capacity across the network, origins and destinations of passengers with bikes, time of day associated with bike rack use, and stop-based density of rack use. Figure 3-22 and Figure 3-23 show screenshots of this version of the dashboard.

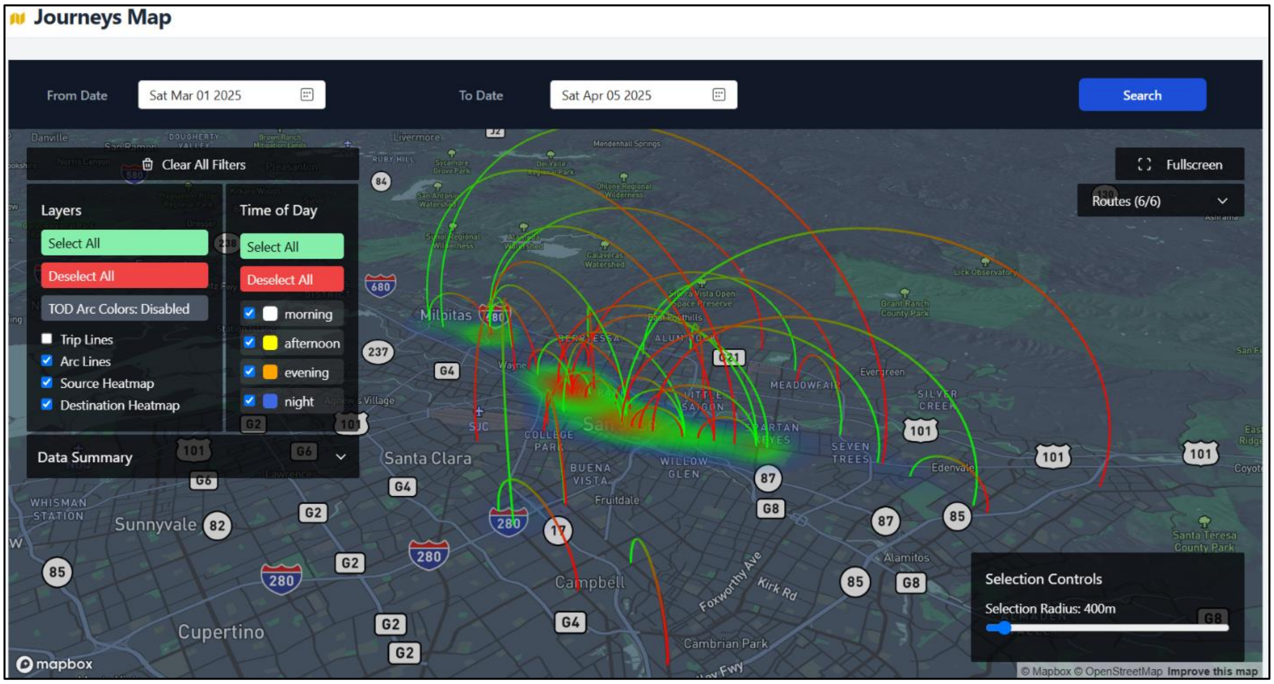
Figure 3-23 shows Sportworks' journey map, which provides origin-destination pairs for passengers with bikes. One benefit of the journey map is its ability to detect instances where one passenger removes their bike and another passenger immediately adds theirs. In these cases, the real-time passenger information does not change; however, Sportworks' system records two passengers, which enhances internal planning and performance management efforts.

Figure 3-22. Sportworks Velolink Website: Stop-based Deployment



Source: Sportworks 2024

Figure 3-23. Sportworks Journey Map



Source: Sportworks 2024

3.7.2 Wheelchair Ramp Deployment (Power BI)

Early in the Project, the project team recognized that meaningful trend analysis requires a large enough dataset, which the on-bus priority seating area sensors are expected to provide once they are installed fleet-wide.

Because only one sensor has been installed (on the test bus), the project team used the thousands of wheelchair ramp deployments already logged by the CAD/AVL system as a proxy dataset. These wheelchair ramp deployments indicate when wheelchair users have likely boarded or exited the bus; however, wheelchair ramp deployments could also occur in the following scenarios:

- Passengers with limited mobility (not using wheelchairs)
- Passengers have heavy rolling items, such as shopping carts or suitcases
- A significant gap between the door and the curb

Although a wheelchair ramp deployment does not necessarily mean that a wheelchair user boarded or exited the bus, this dataset is the closest proxy available fleet-wide.

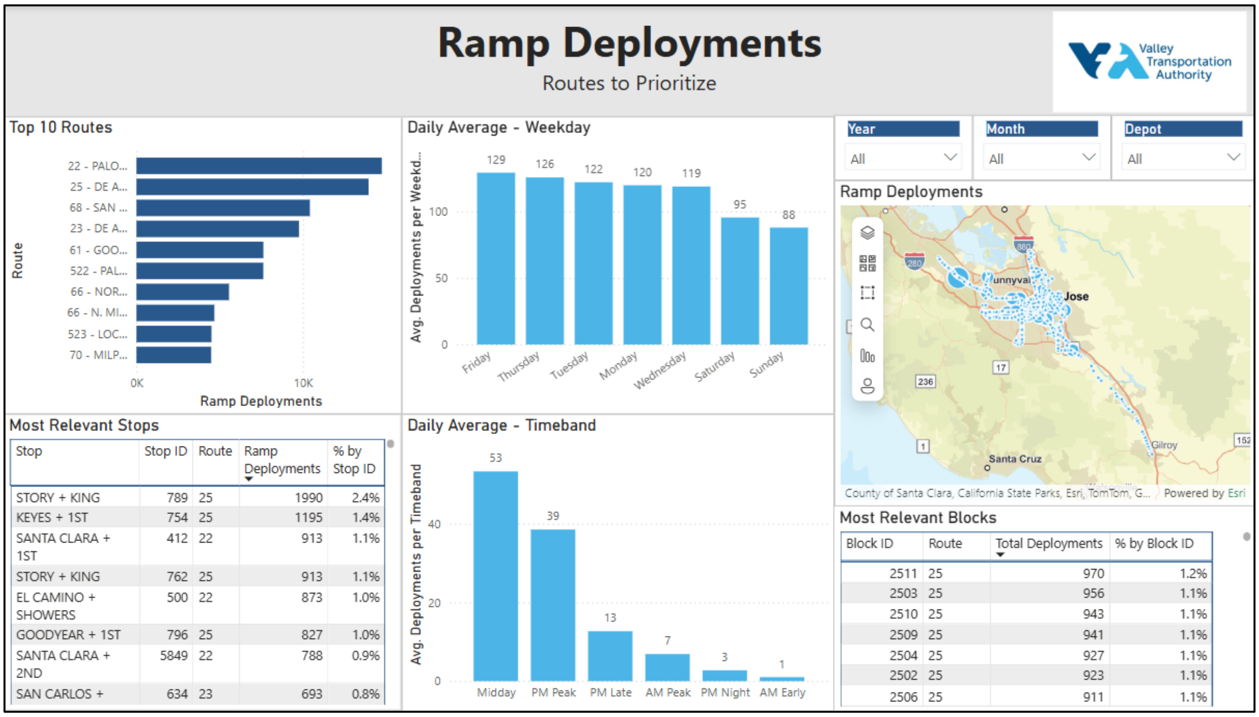
The Power BI report and analysis are a framework and proof of concept; rather than offering a definitive evaluation of current wheelchair ramp use, they illustrate the types of key performance indicators (KPIs) that VTA could monitor once priority seating area occupancy data is available. In Stage 2, this Power BI report could be easily adapted to include actual occupancy data, once priority seating occupancy data becomes available.

Buses are beginning to record initial priority seating occupancy data. However, meaningful insights depend on a larger dataset. Existing fleet-wide wheelchair ramp deployment data would provide insight into potential occupancy trends and a foundational reporting methodology for Stage 2.

Figure 3-24 and Figure 3-25 show the Power BI report that enables users to dynamically slice and filter wheelchair ramp deployment data by year, month, time of day, day of the week, and stop ID for VTA's top 10 routes. An interactive map shows geographic clusters and hotspots, making it easy to identify bus stops with the highest ramp deployment activity within a selected timeframe.

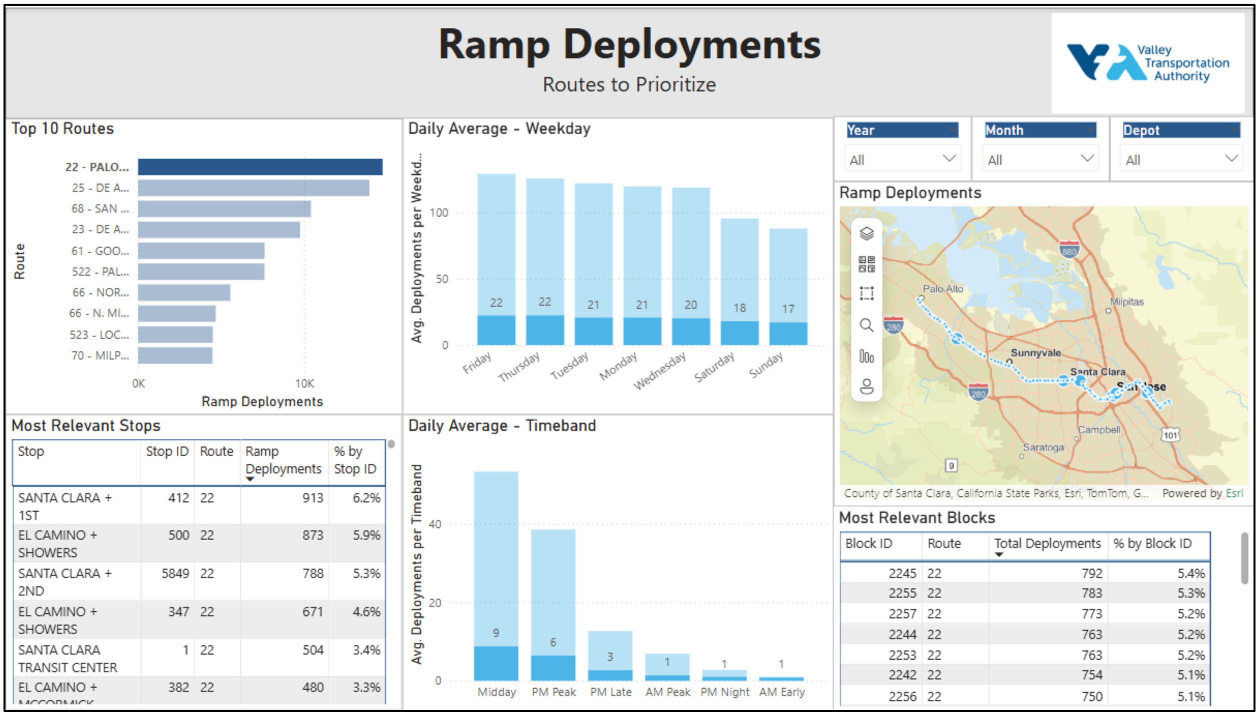
Buses are beginning to record initial priority seating occupancy data. However, meaningful insights depend on a larger dataset. Existing fleet-wide wheelchair ramp deployment data would provide insight into potential occupancy trends and a foundational reporting methodology for Stage 2.

Figure 3-24. Interactive Power BI Report



Source: WSP 2024

Figure 3-25. Interactive Power BI Report (Filtered)



Source: WSP 2024

At this preliminary stage, the dataset consists solely of raw wheelchair ramp deployment counts, without service variables, such as revenue hours, revenue miles, and ridership, to normalize the figures. Although this limitation constrains the depth of analysis, it is acceptable for this exploratory phase. The existing data are intended to demonstrate how sensor data (when fully deployed in Stage 2) can be integrated with broader service metrics. This integration would enable VTA to generate normalized, actionable insights and identify operational or planning hot spots.

The following sections discuss insights related to metrics/KPIs, including time of day, route, and stop.

Route Insights

According to the *Transit Cooperative Research Program Report 100: Transit Capacity and Quality of Service Manual*[15] and Wong et al.'s study, *An Exploratory Study of Encumbered Passengers on Fixed Route Transit,*[16] the average boarding time for a wheelchair user typically ranges from 137 to 300 seconds. This duration includes the time required for boarding or exiting and securement.

The project team followed this guidance on expected dwell times, filtering out ramp deployments with dwell times outside this range. The analysis highlighted that **Route 22 – Palo Alto–Eastridge** had the highest number of wheelchair ramp deployments in 2023 and 2024. This route accounted for 11.8% of the total. The route with the next highest number of wheelchair ramp deployments was **Route 25 – De Anza–VMC–Alum Rock**, which accounted for 11.1%.

The average dwell time during wheelchair ramp deployments was approximately 3 minutes and 40 seconds for Route 22 and 3 minutes and 39 seconds for Route 25.

The project team proceeded to analyze the top 10 routes with the highest number of wheelchair ramp deployments. Table 3-8 shows the complete list.

---

[15] Transportation Research Board. (2013). *Transit capacity and quality of service manual (3rd edition)*. Transportation Research Board, National Academies of Sciences, Engineering, and Medicine. https://www.trb.org/Publications/Blurbs/169437.aspx.

[16] Wong, J., Millard-Ball, A., & Nelson, D. (2021). *An exploratory study of encumbered passengers on fixed route transit*. Journal of Transport & Health, 21, 101070. https://doi.org/10.1016/j.jth.2021.101070.

Table 3-8. Routes with the Highest Number of Wheelchair Ramp Deployments

Route	Total Deployments in 2023 and 2024	Percentage of Total
22 - PALO ALTO - EASTRIDGE	14,740	11.8%
25 - DE ANZA - VMC - ALUM ROCK	13,945	11.1%
68 - SAN JOSÉ DIRIDON - GILROY TC	10,418	8.3%
66 - N. MILPITAS - SANTA TERESA STN	10,237	8.2%
23 - DE ANZA - STEVNS CRK - ALUM ROCK	9,765	7.8%
61 - GOOD SAM - SIERRA & PIEDMONT	7,624	6.1%
522 - PALO ALTO - EASTRIDGE	7,619	6.1%
523 – LOCKHEED MARTIN – SAN JOSÉ STATE	4,506	3.6%
70 – MILPITAS BART – CAPITOL STN	4,488	3.6%

Stop Insights

The filtered dataset revealed that the 10 stops with the highest number of wheelchair ramp deployments were primarily along Routes 25, 22, 23, and 522; Table 3-9 shows a complete list.

Table 3-9. List of Stops with the Highest Number of Wheelchair Ramp Deployments

Route	Stop	Stop ID	Ramp Deployments
25 - DE ANZA - VMC - ALUM ROCK	STORY + KING	789	1,990
25 - DE ANZA - VMC - ALUM ROCK	KEYES + 1ST	754	1,195
22 - PALO ALTO - EASTRIDGE	SANTA CLARA + 1ST	412	913
25 - DE ANZA - VMC - ALUM ROCK	STORY + KING	762	913
22 - PALO ALTO - EASTRIDGE	EL CAMINO + SHOWERS	500	873
25 - DE ANZA - VMC - ALUM ROCK	GOODYEAR + 1ST	796	827
22 - PALO ALTO - EASTRIDGE	SANTA CLARA + 2ND	5,849	788
23 - DE ANZA - STEVNS CRK - ALUM ROCK	SAN CARLOS + BASCOM	634	693
522 - PALO ALTO - EASTRIDGE	EL CAMINO + SHOWERS	347	684
22 - PALO ALTO - EASTRIDGE	EL CAMINO + SHOWERS	347	671

Day of the Week and Time of Day Insights

In both 2023 and 2024, weekdays had a higher average number of wheelchair ramp deployments than weekends. The variation among weekdays was relatively small, ranging from an average of 119 to 129 deployments per day.

When analyzing the time of day, the midday period consistently had the highest number of average daily wheelchair ramp deployments, with approximately 53 per day, followed by the PM peak, with an average of 39 deployments per day.

When combining day of the week and time of day, the data showed that Route 25 during midday on Tuesdays, Wednesdays, and Fridays had the highest average number of daily wheelchair ramp deployments in 2023 and 2024. Similarly, Route 22 had its highest number of wheelchair ramp deployments during midday on Thursdays and Fridays. This pattern was consistent across the remaining top 10 routes, indicating that weekday middays are the most active period for wheelchair ramp deployment systemwide.

Overall Insights

Overall, this Power BI report highlights the following key insights:[17]

- **Route 22 – Palo Alto–Eastridge**. This route had nearly 12% of total wheelchair ramp deployments, with an average wheelchair ramp deployment of 3 minutes and 40 seconds.
- **Time Period**. System-wide, weekday midday (9:00 AM to 14:29 PM) had the highest number of wheelchair ramp deployments at approximately 53 deployments per day.
- **Stops.** The highest number of wheelchair ramp deployments occurred along the 22 and 25-Story + King, Keyes+ 1st Street, and Santa Clara + 1st Street stops.

Issues with the Dataset

The project team inspected the wheelchair ramp deployment data to ensure its validity. Issues with the data are often related to wheelchair ramp deployments at the first and last stops for each route and dwell times. On routes with the highest number of ramp deployments, the beginning and end of the route had the largest number of deployments.

[17] Although these insights come from wheelchair ramp deployment data, not priority seating occupancy data, they reflect the general trends expected on wider application of sensing technology from this Project.

However, these events often recorded a dwell time of zero seconds, suggesting that many instances may be bus operators testing the ramp before entering service.

Additionally, the dwell time data contains many negative values, indicating potential inaccuracies in data collection. Because of these issues, the project team recommends not relying on the current dwell time field. Instead, it recommends capturing more accurate dwell times using door open-to-door close timestamps, typically available through automatic passenger counter (APC) data.

Future Implementations

This Power BI report demonstrates the types of data that can be gathered and the insights it can generate. The analysis of route, stop, day of the week, and time of day reveals usage patterns that could support VTA's efforts to better serve wheelchair users as they travel on VTA buses.

Although wheelchair ramp deployment data does not directly relate to priority seating occupancy, it provides insight into high-level trends that could set the foundation for analysis once priority seating area occupancy data becomes available.

Wheels on the Bus Report

Chapter 4:

Anticipated Costs and Benefits of At-scale Implementation

4. Anticipated At-scale Costs and Benefits

4.1 Analysis Summary

The Project Team outlined cost and benefit categories; During Stage 2, the Project Team would develop a custom BCA methodology applied through the FTA-sponsored bus yard automation program.

A BCA is a systematic process used to evaluate the anticipated economic costs of a proposed infrastructure project. A BCA involves identifying, quantifying, and comparing the expected benefits and costs over a specific timeframe.

A BCA aligns with a multiyear horizon that corresponds to an asset's anticipated lifespan. It incorporates escalation rates and differentiates between capital expenditures and ongoing operation and maintenance costs.

A BCA includes a base scenario that represents current conditions (business as usual today) and multiple alternative scenarios based on factors such as the number of vehicles retrofitted or the technologies adopted. A BCA may also include sensitivity testing on cost factors.

BCAs are typically developed in pursuit of USDOT discretionary grants and are therefore aligned to specific guidelines.[18] However, this Stage 1 BCA lists only costs and benefits across technologies, with all values listed in 2025 dollars.

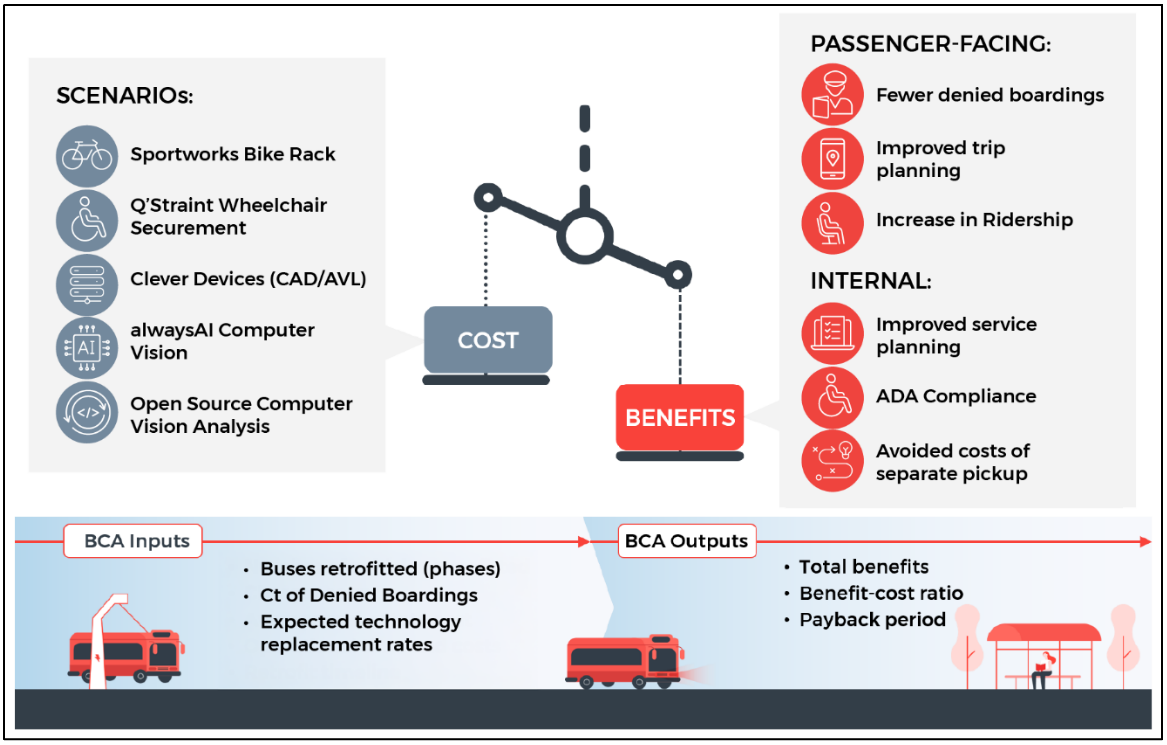
The project team would include a more rigorous BCA in Stage 2. This Stage 2 BCA would build on the project team's experience developing unique BCA methodologies for the Federal Transit Administration (FTA) grants for automated battery-electric buses.

Figure 4-1 shows the methodology used for developing BCAs.[19]

[18] https://www.transportation.gov/grants/dot-navigator/what-is-a-benefit-cost-analysis.

[19] See *Financial Considerations with Bus Automation* describing the custom BCA methodology in this whitepaper: https://www.wsp.com/-/media/hubs/us/fact-sheets/bus-automation_white-paper_final.pdf. 2025 project announcement: https://www.wsp.com/en-us/news/2025/capmetro-yard-demonstration.

Figure 4-1. BCA Methodology for Investing in Occupancy Tracking Technology[20]



Source: WSP 2025

Because real-time occupancy tracking technologies are not yet widely adopted by transit agencies, fleet-wide pricing is not currently available. Therefore, this BCA considers costs for one bus instead of costs across all 440 buses in VTA's fleet. However, Stage 2 would include a more detailed discussion with vendors on projected scaling of costs. Scale is discussed in individual sections below, and Section 4.4*, Stage 2 Considerations*.

> This BCA breaks down the costs for all technologies piloted and their anticipated benefits. Stage 2 would analyze at-scale costs as part of a more rigorous BCA.

[20] The benefits and costs illustrated here intend to be representative, not comprehensive for the sake of readability. The cost and benefit sections, respectively, provide the complete list of these elements. Stage 2 would include a BCA model that summarizes this information holistically.

4.2 Costs

This section discusses the vendor-specific costs identified during Stage 1. The base case for these costs is VTA's operations as they exist today, without retrieving occupancy data from priority seating areas and bike racks. Only the extra capital and operating costs associated with implementing the technology needed to collect occupancy data are considered.

Although these estimated costs are intended to be representative, they are subject to change because occupancy tracking is still in development. Stage 1 primarily focused on accessing historical data; Stage 2 would refine the cost estimates related to tracking priority seating area and bike rack occupancy in real-time.

Table 4-1 summarizes the costs, calculations, and assumptions with detailed breakdowns provided in the vendor-specific sections that follow. Because this Project is a first-of-its-kind, Table 4-1 intentionally omits a grand total because of variabilities in costs.

Table 4-1. Summary of Costs Across the Occupancy Technologies Tested in Stage 1

Vendor	Cost Description	Quantity	Cost ($2025)[1]
Sportworks (Bike Rack)	Bike rack (3-positions)	One-time per bus	$2,231[2]
	Velolink subscription	Annual per bus	$348
Q'Straint (Wheelchair Securement)	Q'POD tensioner with electrical sensor	One-time per bus	$2,500
Clever Devices (CAD/AVL)	Stage 1 labor	One-time Stage 1	$21,600
	(Projected Stage 2 multiplier)		10x
	Stage 2 projected labor	One-time Stage 2	$216,000
alwaysAI (Computer Vision)	Total licensing (pilot)	One-time	$40,000
	App activation	One-time per bus	$5,000
	Maintenance	Annual per bus	$6,000
Open-Source Computer Vision Analysis	Compute, edge devices, staff time	One-time Stage 2	To be determined
Amazon Web Services (AWS; Real-time)	Staff and cloud compute costs to integrate occupancies into GTFS-RT feed	Annual	$2,000 to $6,000

[1] Cost in 2025 United States Dollars.

[2] This cost includes about $1,500 for the three-position rack, which is assumed to be standard on all new buses. This total cost also reflects the hardware enabling sensor data collection for Velolink (for example, Velolink kit including counter harness, sensors, and connectors). Section 0, *Sportworks*, describes this breakdown further.

As occupancy technology continues to evolve and attract more interest from transit agencies, the associated costs may decrease, thereby improving the business case for implementing the technology. For example, as agencies develop an increased interest in tracking real-time data, some Original Equipment Manufacturers (OEMs) may begin including these products as part of the standard equipment package installed during bus manufacturing, instead of leaving an agency to retrofit these technologies after the fact.

4.2.1 Costs by Vendor

Sportworks

Table 4-2 summarizes Sportworks hardware costs, focusing on three-position bike racks in use by VTA. Sportworks also provides a two-position bike rack (Apex-2), which is not listed in the table. The Apex 2 rack (without any associated technology) costs $1,156, while the corresponding Velolink hardware costs an additional $749.

Table 4-2. Sportworks Hardware Costs

Fee Category	Element	Cost	Notes
A	Apex-3 bike Rack (three-positions)	$1,472	Standard 1-year warranty from time of shipment date[1]
B	Velolink Hardware, Apex-3, Base Cost	$799	Velolink compute system (kit including counter harness, sensors, connector kit, and cellular modem)
C	Velolink Hardware, Apex-3, with discount	$759	Factors in 5% discount for an agency transitioning to a new hardware kit[2]
A+C	One-Time Total Bike Rack Hardware Cost (Apex-3)	$2,231	

1 https://www.sportworks.com/terms-and-conditions-of-sale.

2 Sportworks shared, "We strongly recommend using our new harness, sensor, and connector kit for optimal reliability. While we do not offer a recycling program, we understand the transition cost and are willing to provide an additional 5% discount on the entire hardware kit to make the upgrade more attractive."

Table 4-3 lists software costs for the Sportworks Velolink technology, which directly transmits bike rack occupancy data to Velolink's web dashboard and API suite. This annual subscription cost is not scaled across the entire 12-year useful life of a bus because this technology is still being developed. Stage 2 would provide better scaling costs over a longer time horizon and bus count. Meanwhile, other cost considerations are listed in Table 4-4.

Table 4-3. Velolink Software Costs

Fee Category	Element	Cost	Notes
A	Velolink Stage 1 Costs	—	Equipment donated
B	Subscription Cost	$29	Per unit per month
C	Annual Per Bus Velolink Subscription Cost	$348	Scaled for 12 months

Table 4-4. Additional Cost Considerations for Sportworks

Factor	Estimate	Notes
Fleet-wide Adoption Discount on Retrofitted Hardware	10%	At-scale discount
Harness-potential Damage and Corrosion Factor	—	Although the plastic and rubber connectors within a harness may become brittle, no data is currently available regarding the timeframe or average mileage after which the harness may need to be replaced. From a fleet-wide adoption perspective, the corrosion seen on the test bus was likely caused by the connectors being left unused and uncapped.
Operation and Maintenance Cost	—	Estimating no additional costs caused by collecting occupancy data. Additional data are needed to validate.
Staff Time	—	Donated vendor time. Expecting none from vendor, not a product yet. VTA staff time
VTA Engineering Technician Time	2 to 3 hours	Per bus installation at-scale

One other consideration is the hardware's lifetime expectancy. Sportworks connectors are sealed against water and dust ingress with rubber gasket seals. Additionally, the Velolink module has been designed to repel water, moisture, or corrosive agents, and is resistant to shock and vibration. The magnetic reed switch sensors that detect occupancy are rated for millions of activations. For this reason, these various components should outlive a bus' useful life. That said, the magnets which open and close the magnetic reed switches on the bike rack tend to fall off if the adhesive is improperly applied, or after extended exposure to the elements. Neither the project team nor Sportworks have an estimate at the rate this will occur. They are inexpensive to buy and easy to reapply, however the costs would add up over time.

Q'Straint

The project team piloted Q'Straint technology for wheelchair securement. Q'Straint donated two Q'POD tensioner units to VTA for testing in Stage 1. As shown in Table 4-5., these units cost $2,500 each.

Table 4-5. Q'Straint Hardware Costs

Fee Category	Element	Cost	Notes
A	Q'Straint Q'POD Tensioner with Electrical Connection (Sensor)	$2,500	This amount does not include the Q'POD wheelchair restraining system that is already installed on the test bus. Different models of Q'PODs are installed across the VTA bus fleet. Q'Straint donated two tensioner units to VTA for this pilot program.
B	Q'Straint Quantum	$14,000	This semi-automatic wheelchair restraint was not tested during Stage 1 because passengers expressed concerns with rear-facing seats. Unlike the Q'POD, agencies can buy these units directly from Q'Straint. See Section 3.2, Vendor Selection, above, for a detailed explanation of the selection criteria.

The Q'Straint Q'PODs come with a 5-year limited warranty that covers "factory defects in materials and workmanship." Therefore, agencies are responsible only for maintenance not related to manufacturing flaws.[21]

Unlike the original Q'POD design, which does not require tension to operate, the new Q'POD incorporates a sensor that only activates with an estimated 40 to 70 pounds of tension. This requirement may result in quicker identification of any manufacturing defects, such as issues with the belt, stitching, or tensioning mechanism.

Notably, agencies must coordinate either with the vehicle's OEM or the OEM for the priority seating area to purchase these tensioners. Agencies cannot buy these units directly from Q'Straint, which is likely to increase the equipment cost.

Clever Devices

During Stage 1, VTA's CAD/AVL vendor, Clever Devices, helped integrate sensor data so that VTA could access the data directly through existing systems.

Table 4-6 shows the costs for Stage 1 and the cost projections for Stage 2. Stage 2 includes a multiplier of 10 times in cost. Assuming that the vehicle state file captures wheelchair occupancy in the June 2025 software update (pending as of this writing), Clever Devices' key role in Stage 2 would be to enable real-time occupancy tracking.

[21] https://www.qstraint.com/qstraint-register-your-product.

Table 4-6. Staff Labor Cost Projections for Clever Devices' Sensor Integration

Fee Category	Project Stage	Element	Cost	Notes
A	Stage 1	Systems engineer labor rate	$540	Per hourly cost according to Clever Devices
B		Hours	40	Testing and data collection of bike rack and Q'POD tensioner sensor with IVN
AxB		Actual labor cost	$21,600	Five hours a week over eight weeks
C	Stage2 Projection	(Projected Stage 2 multiplier)	10x	Assumed cost for Stage 2 based on scope relative to Stage 1
AxBxC		Projected Clever Devices' cost	$216,000	Assumed development to enable real-time

alwaysAI

The total cost for alwaysAI's computer vision technology is $40,000 for a one-time licensing fee and $6,000 annually in maintenance cost for a minimum of three years. These fees are organized into four primary categories that reflect the flow of AI implementation (Table 4-7):

Table 4-7. alwaysAI Cost Breakdown

Fee Category	Element	Cost	Notes
A	Virtual data capture appliance	10,000	One-time perpetual licensing fee
B	Virtual application appliance-priority seating analysis	30,000	One-time perpetual licensing fee
A+B	Total one-time licensing fee (pilot)	40,000	
C	Application activation license per bus	$5,000	One-time perpetual site licensing fee (VTA)
D	Annual maintenance cost per bus	$6,000	20% of element B

This structured approach enables rapid and efficient deployment, thereby helping agencies cost-effectively leverage AI while seamlessly integrating the technology into existing offerings. The model is designed to support scalable, enterprise-wide adoption.

A. One-time Virtual Data Capture Appliance Licensing

Vision AI begins with a data capture appliance that facilitates recognizing "wheels" in the priority seating area through computer vision. The initial data capture is required to train the AI models that power the occupancy tracking application.

In addition to the initial data capture, the implementation phase includes assessing the site and infrastructure, evaluating the cameras, and configuring application parameters. This implementation phase serves as an initial configuration phase of the application appliance licensing, allowing alwaysAI to demonstrate the application's capabilities and performance.

B. One-time Virtual Vision AI Application Appliance Licensing

Perpetual licensing of an AI application appliance permits deployment of the proposed use case application. A virtual appliance describes the deployment package of the AI application for target hardware. This approach would allow VTA to capitalize on its existing infrastructure while simplifying adoption by minimizing sales and implementation barriers.

C. One-time App Activation Licensing for Each Bus

A one-time app activation licensing fee (per site) would grant VTA a perpetual right to use this "wheel" recognition application at VTA. This one-time fee includes all initial software customization required to support a site and would allow VTA to deploy and run multiple instances of the application within that location. Ongoing access to software updates, support, and maintenance are subject to a separate annual fee. For this Project, the one-time app activation licensing would be considered VTA's "mobilization" setup per location.

D. Annual Application Maintenance and Support

This option includes ongoing support, software configuration and maintenance, integrations into enterprise systems and sensors, AI model updates, bug fixes, and feature enhancements to support the full appliance lifecycle during the license term. With this option, 20% of the license fee would be charged annually with a 3-year minimum. This cost would be $6,000 per site.

alwaysAI also shared that each bus would need an edge (on-bus) device to run alwaysAI's inference engine locally with the existing camera feed. The edge device would cost approximately $1,000 per unit. On-bus installation, calibration, and initial verification would be handled by alwaysAI or designated VTA integration partners.

Open-source Computer Vision Modeling

As described above in Section 3.6*, CCTV-Based Occupancy*, this final cost category relates to VTA's use of an open-source computer vision model to detect priority seating occupancy through its CCTV footage. Agencies with in-house software development capabilities could benefit from implementing an open-source model, allowing for greater control over the data that is captured.

Stage 1 focused mainly on physical hardware pilots with Q'Straint, Sportworks, and Clever, along with alwaysAI performing a preliminary computer vision assessment. As a result, this section does not include specific costs; however, it provides a framework for the categories of costs associated with implementing an in-house, open-source model.

As shown in Table 4-8, at the simplest level, there are two phases and associated costs associated with implementing an in-house, open-source model.

Table 4-8. Open-source CCTV-based Occupancy Costs

Phase	Element	Notes
Model Training	Staff time	Time for calibrating a model for specific object(s) of interest (such as wheelchairs and bikes) that are not well captured by the baseline model.
	Computing resources	This element requires a machine with enough processing power for model training. Options include local workstation machines and cloud-based machines from different cloud service providers.
Model Application	Central server room	This element accounts for the scenario where CCTV footages are transmitted **back to central server room** in real-time or near real-time. Trained model(s) would be applied to extract occupancy insights, and outputs would be post-processed and published from the central server room.
	Edge (on-bus) computing units	This element accounts for the scenario where CCTV footages are **processed on the bus** using trained model(s). Outputs would be post-processed and made available from either the bus or after being transmitted to the central server room.

Some factors that drive the cost for each of these elements are staff time, the cost of securing a machine for model training, and potential upgraded hardware and ITS equipment to accommodate the extra data transmittals for the model application phase.

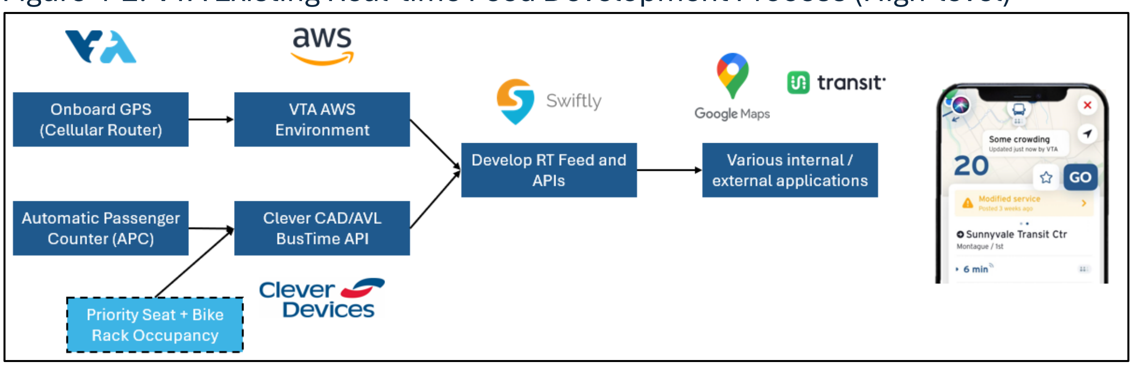
Note that although model training usually requires specialized machines with reasonably powerful GPU capacities, model applications on trained models can usually be handled by typical laptops and edge computing units.

4.2.2 Real-time Capability

Section *4.2.1, Costs by* Vendor described the key cost categories related to using historical occupancy data. This section discusses the costs associated with using real-time data.

Figure 4-2 shows how vehicle location and APC data flow from on board a bus, through Amazon Web Services (AWS) and Swiftly, and to a passenger. This Project requires integrating data from new occupancy sensors (illustrated in light blue).

Figure 4-2. VTA Existing Real-time Feed Development Process (High-level)



Source: WSP 2025

For more information about the technology needed to gather and use real-time data. See Section *6.1.3, Deployment Readiness: Real-time Occupancy for Passengers*.

The following are real-time components with cost implications:

- **API Access:** Clever Devices and Sportworks would need to enable access to their occupancy data through real-time APIs. Today, VTA passengers using Transit App or Google Maps for transit arrival times rely on such API feeds. These feeds communicate location and trip information from VTA systems within seconds of vehicle movements.

  Section 3.5.3, *Hardware-in-the-Loop*, describes the need for Clever Devices' vehicle state file to provide real-time priority seating occupancy data that VTA can access through the BusTime APIs. Clever Devices' associated software development cost to enable this real-time functionality is currently unknown, but it is assumed to be 10 times that of the cost associated with Stage 1.

Sportworks' APIs are currently available as a beta; these would need to be available more widely before being implemented on VTA buses. The cost of Sportworks' Velolink quoted above includes this API cost.

The project team would pilot these real-time capabilities in Stage 2.

- **Specification Change:** The transit industry would need to convene to modify the GTFS-RT specification through which agencies communicate real-time data to passengers via mobile apps. This change would enable VTA to communicate priority seating area and bike rack occupancy data to passengers via Transit App (or other third-party apps).

  Alternatively, VTA could find a way to avoid changing the specification, which would avoid needing transit industry consensus or convincing software providers of any change; however, that approach would require VTA to develop and market a new mobile app. For more information about the process of developing a mobile app, see Section 0, *Mobile App Development Trade-offs*.

  Modifying the GTFS-RT specification is a more time-intensive step; it would require VTA staff time and development from partners, such as Transit App and Swiftly. For more information about modifying the GTFS-RT, see Section 0, *Process for Updating* the GTFS-RT. Changing the specification would likely entail a one-time staff cost.

- **VTA Data Infrastructure:** To integrate the priority seating area and bike rack occupancy data into its existing *Trip_Updates* feed (used by Transit App), VTA would need to transform data in AWS. This Project assumes that VTA currently manages its real-time data feed, either internally or through established partnerships. As a result, adding the occupancy field is expected to incur minimal additional management costs.

Table 4-9. provides a potential cost range of VTA data infrastructure, which would be validated in Stage 2. These AWS technologies are involved with retrieving data from vendors, merging it with existing location and trip-based data, archiving it for future troubleshooting needs, and providing it to third-party applications.

Table 4-9. Costs for Including New Occupancies Within the Existing Real-time Pipeline

Component	Notes	Estimated Cost[1]
Data Integration/Extract-Transform-Load, One-time	Append bike and wheelchair fields to existing trip_update feed (one-time)	$1,000 to $5,000
Compute/AWS Lambda	Minimal stream compute; assume <1 million updates per day	$100 to $1,000 (very low usage)
Storage (Amazon S3 or Database if Needed)	Only if archiving occupancy logs (optional)	$100 to $500
Maintenance labor (Fractional)	Occasional development tweaks (0.02 to 0.05 full-time equivalent, or a few days during the first year)	$2,000 to $5,000
Estimated Annual Cost Range		$2,000 to $6,000

[1] These cost ranges are approximate based on preliminary research. During Stage 2, the project team would more closely analyze the real-time pipeline (as part of the GTFS-RT specification change process) and revisit these estimates.

The project team has begun initial discussions regarding VTA's real-time feed design, which would be continued during Stage 2. One of the challenges of using a third-party managed, real-time feed would be the need for third-party support to reflect GTFS-RT specification changes. The third party would also need to build the API feeds to enable these new occupancies into GTFS-RT trips.

Alternatively, a VTA-created and hosted real-time feed would require a cloud setup with high uptime (for external real-time app consumption). The costs of the cloud services described in Table 4-9. above are nominal, with larger support staff time for real-time monitoring and maintenance.

For more information about tracking and transmitting real-time occupancy data, see Section 6.1.3, *Deployment Readiness: Real-time Occupancy for Passengers*.

4.3 Benefits

The Project aims to provide agencies and passengers with priority seating areas and bike rack occupancy data in real-time.

As discussed in Section *2, Introduction and Project Overview,* the analysis conducted in Stage 1 provides a framework for the project benefits.

Stage 2 would seek to build a more comprehensive return-on-investment analysis in partnership with VTA and technology partners. This analysis would scale the benefits and costs over a longer time horizon.

Table 4-10 lists the project benefits based on whether they benefit agencies or passengers and whether they can be quantified. As a BCA technicality, the benefits include several avoided costs, such as avoided regulatory expenses or supplementary paratransit pickups.

> Greyhound and the New York City Metropolitan Transit Authority have spent millions in court addressing legal complaints related to Americans with Disabilities Act (ADA) violations.
>
> Proactively investing in occupancy technology for passengers in wheelchairs could help reinforce VTA's commitment to its passengers and avoid steep regulatory costs.

Table 4-10. List of Project Benefits

Benefit Category	Topic	Potential Data Sources	Quantifiable	Monetizable[1]
Passenger-facing (Section 4.3.1)	Fewer denied boardings	Call center or others	✓	✗
	Positive customer experience	Feedback surveys, Transit GO[222]	✓	✗
	Potential increase in ridership[3]	Ridership studies	✓	✓
Internal to Agency (Section 4.3.2)	Improved service planning	CAD/AVL, on-time performance	✗	✗
	ADA compliance	Transit industry precedents	✓	✓
	Avoided costs of separate pickup	Staff and vehicle operations cost	✓	✓

[1] "Monetizable" indicates that this benefit can be realistically assessed as a monetary benefit that improves the return-on-investment metrics of this Project. "Realistically" means that the project team believes this methodology has a sufficiently robust rationale, while requiring further discussion with agency staff.

[2] Transit App released a feature called "GO," which uses real-time mobile location data to improve accuracy of a trip's real-time location as viewed by passengers through the Transit App. "GO" also includes a rate-my-ride feature referenced here. For more information about "GO," see Section 4.3.1.1, *Fewer Denied Boardings (Historical Data)*

[3] The project team acknowledges that drawing causality between ridership for passengers with "wheels" and occupancy data tracking technology could be challenging. However, Stage 2 would further analyze the viability of including this metric as a benefit.

4.3.1 Passenger-Facing Benefits

Improving the passenger experience for wheelchair users and those with bikes is at the core of this Project. This section provides a framework to evaluate passenger-facing benefits from both historical and real-time occupancy data.

Unlike agency-facing benefits, these passenger-facing benefits can be more difficult to quantify because such information is available only after assessing passenger feedback.

[22] Transit App released a feature called "GO," which uses real-time mobile location data to improve accuracy of a trip's real-time location as viewed by passengers through the Transit App. "GO" also includes a rate-my-ride feature referenced here. For more information about "GO," see Section 4.3.1.1, *Fewer Denied Boardings (Historical Data)*.

The following benefit categories are considered:

- Fewer denied boardings
- Improved trip planning
- Increased ridership

For a complete summary of how the Project could benefit passengers and disadvantaged communities, see Section 2.2, *Community Impact*.

4.3.1.1 Fewer Denied Boardings (Historical Data)

Even without real-time visibility, occupancy data can improve service planning and indirectly enhance passenger experience. Riders are less likely to encounter denied boardings or overcrowded priority seating areas on routes where agencies have adjusted service in response to historical trends. The following two data sources can help quantify these benefits:

- **Post-implementation Survey Results:** These results can reflect perceived improvements in trip reliability and accessibility.
- **Transit App Engagement Metrics:** Metrics such as increased feature usage or higher trip planning success rates may indicate growing trust in the system. In early 2024, Transit released instant "Rate-My-Ride" surveys with passengers who use "GO" for trip planning.[23] This form of near real-time passenger feedback demonstrates a way to further quantify the benefits of this Project. During Stage 2, the project team would coordinate with Transit App on appropriate GO survey questions to capture these impacts (for example, "Did you bring a bike or wheelchair on board this bus? If so, how was your experience?").

VTA noted that there is a difference between *complaints about* denied boardings and actual instances that can be verified through the data that this Project would provide (that is, insufficient space on board the bus). Therefore, the data sources to track fewer denied boardings would be a combination of post-implementation survey results and Transit App engagement metrics.

---

[23] https://resources.transitapp.com/article/441-rate-my-ride-instant-surveys-with-go.

Most BCAs for USDOT grants include a dedicated discussion to monetize benefits through existing standards around time, injuries, or other methods. Stage 2 would include a similar monetization analysis for these customer experience–related benefits.

4.3.1.2 Improved Trip Planning (Historic or Real-time Data)

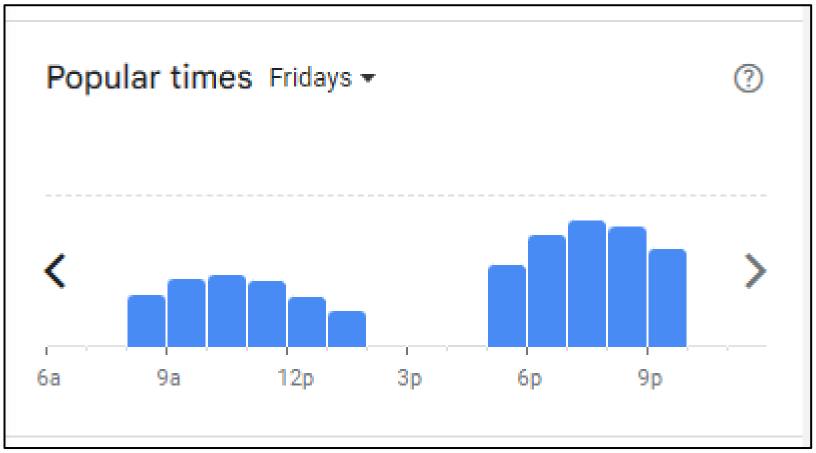
Today, real-time passenger data about expected bus arrival times or trip cancellations enables passengers to plan their trips with more ease. Similarly, priority seating area and bike rack occupancy data would help passengers plan their trips. Both real-time and historical data are useful; historical data includes location and timestamped data on how many priority seats or bike rack slots were available at a given time.

Historical data could help to influence travel behavior for passengers with flexible schedules. Although not easily monetizable, historical data on specific blocks that tend to have little to no available bike rack or priority seating space could encourage passengers to consider alternate itineraries.

Although VTA strives to accommodate passengers through measures such as service adjustments, the availability of baseline historical data establishes a valuable foundation for improving the trip planning capabilities of passengers.

Figure 4-3 shows how Google Maps shows peak time periods of retail activity. VTA could use a similar interface to provide passengers with occupancy data based on historical occupancy.

Figure 4-3. Google Maps' Historic Retail Activity Levels



Source: Google Maps

With real-time occupancy data, passengers would be able to make more precise decisions about their trips; they would be able to choose trips where space is available, reducing uncertainty and improving their overall confidence in fixed-route service. This capability would be particularly valuable for passengers who have previously experienced denied boardings or who rely on consistent, accessible boarding options.

Figure 2-3 shows a potential illustration of this information augmented onto Transit App. This illustration was made solely by the project team to communicate the type of information that would be available. During Stage 2, the project team would collaborate with Transit App to define how to update the GTFS-RT specification and explore UI/UX designs.

With only two priority seats and three bike rack slots, real-time data may not reliably reflect whether a passenger can board a specific bus. For example, a bicyclist could observe that two bike slots are available when leaving their home, only to find them occupied when they arrive at the bus stop. In contrast, APC loading data has a larger margin for predictability; a bus is unlikely to go from 1 of 3 loading (indicating plenty of seats available) to 3 of 3 loading (indicating overcrowding) quickly.

As more data becomes available in Stage 2, the project team would analyze situations where there is a rapid change in occupancy in a short time, which would influence the utility of such real-time information.

4.3.1.3 Increased Ridership

In both historical and real-time implementations, increased boardings among bicyclists, riders with strollers, and others with wheeled devices, especially on routes where demand has historically exceeded on-board capacity, are possible.

Although it may be difficult to directly attribute behavioral shifts to the implementation of occupancy data tracking, qualitative feedback and long-term ridership trends may offer insight into these benefits.

Because ridership counts influence FTA funding for formula-based grant applications, occupancy data tracking presents an opportunity to increase VTA's visibility for future federal and state funding streams.

As occupancy data tracking technology matures and as more data is integrated into passenger tools, more passengers would benefit. During Stage 2, the project team would estimate a break-even point to help agencies evaluate the long-term return on investment from both an operational and customer experience–related perspective.

4.3.2 Internal Benefits

Stage 1 showed how VTA can collect time- and location-stamped occupancy data for the bike racks and priority seating areas. With this information available historically at the end of Stage 1, the project team identified the following VTA-facing benefits:

- Improved service planning capabilities
- Avoided regulatory compliance costs
- Avoided supplementary pickup costs passengers using a mobility device

The last two of these benefits are directly quantifiable and monetizable, and the first benefit is rooted in improving passenger experience. Service planning improvements are a core part of this Project's inception; however, to reasonably quantify these types of benefits, further discussion would be required during Stage 2.

The Project's first key milestone was gaining access to VTA's historical occupancy data; this milestone was achieved on Buses 4403 and 3402. When this data is available across a larger sample of buses, it would show how often the bike rack and priority seating areas are fully occupied. Just as APC data demonstrates bus crowding, this occupancy data would enable agencies to quantify the problem instead of relying on anecdotes. Even historical occupancy data can help VTA validate and act on complaints that passengers report to the call center.

4.3.2.1 Improved Service Planning Capabilities

The first agency-facing benefit from this occupancy data is its ability to improve service planning, thereby reducing instances of denied boardings and potentially improving on-time performance.

Passengers who bring "wheels" on the bus want to board without issues related to occupancy or other factors. For this reason, this planning-level analysis is fundamental to supporting passengers. Although accessing real-time occupancy data helps make trip planning easier, certain trips inevitably have lower occupancy availability, which could inhibit bringing "wheels" on board.

Using historical occupancy data, VTA's Service Planning department can help to minimize situations where passengers need to change their journeys (that is, planning to wait for the subsequent bus) because of a lack of space.

As described in Section 3.7, *Reporting Capabilities*, occupancy data can identify where and when excess demand exists. Parameters for analyzing demand would consist of the following:

- Operational (for example, scheduled block, trip, and route)
- Geographic (for example, stop location, origin, destination)
- Temporal (for example, time of day, day of week, and month)

VTA could monitor accessibility needs through this new data stream and evaluate when vulnerable passengers are unable to use the priority seating area because of a lack of space.

Historical occupancy data trends could inform service planning by helping align dwell times with the expected boarding and alighting times for each scheduled block. A schedule that more closely reflects the actual time bus operators need across a block would take pressure off the bus operators if they appear to be behind schedule, or even worse, running early. Alleviating one part of the schedule adherence issues could improve the experience for both staff and passengers alike.

4.3.2.2 Avoided Regulatory Compliance Costs

This Project recognizes an obligation to adequately serve the disabled community, per federal guidelines. Although transit is a public service, agencies can be severely fined by USDOT or the public for non-compliance with ADA regulations. This Project proactively enables VTA to comply with ADA guidelines and avoid such costs. The Project specifically supports compliance with FTA's guidance to continue receiving Section 5307 (urbanized formula grants) and 5310 (enhanced mobility) federal funds. It also helps monitor compliance with ADA service availability, per USDOT and FTA guidelines.[24]

---

[24] Two federal regulations guide the benefits associated with this Project: USDOT ADA Regulations and FTA Title VI Circular.
(1) U.S. Department of Transportation. 49 CFR Part 37 – Transportation Services for Individuals with Disabilities (ADA), https://www.ecfr.gov/current/title-49/subtitle-A/part-37. This guidance defines accessibility requirements for fixed-route buses, including wheelchair securement areas and boarding assistance. It specifies obligations for accommodating mobility devices and minimizing denials of service.

Investing in occupancy data technology would help VTA proactively demonstrate its commitment to providing equitable service for passengers with disabilities, helping to avoid reputation challenges and potential legal costs associated with non-compliance. Similar challenges have been encountered by Greyhound, the private intercity bus operator, and the New York City Metropolitan Transportation Authority's subway system. If these entities had invested in accessibility-focused technology, they might have been able to avoid their outcomes.

In 2016, Greyhound settled a Department of Justice (DOJ) complaint involving nationwide violations of the ADA, agreeing to over $3 million in payments to more than 2,100 individuals. [25] Per the settlement, the company frequently had broken wheelchair lifts. Courts required Greyhound to implement system-wide ADA reforms, such as hiring an ADA compliance manager, improving ADA training, ensuring equal treatment at rest stops, and quarterly reporting to the DOJ. Similarly, NY MTA subway spent over $3 million in a case in which disability rights advocates filed a class action lawsuit because of chronic elevator outages and the lack of system accessibility.[26] The courts required the MTA to include elevator installation and continued maintenance in any station renovations or upgrades.[27]

These cases could have been avoided by investing in technology that proactively demonstrates a commitment to equitably serving passengers with disabilities. VTA can avoid reputational damage and regulatory costs by thoughtfully investing in occupancy technology supporting the ADA community.

4.3.2.3 Avoided Supplementary Pickup Costs

Through occupancy data technology, VTA could also avoid incurring extra operational costs. VTA's *Equitable Access for Non-Ambulatory Fixed Route* policy from 2019 indicates that VTA must give priority access to priority seating on buses to passengers using wheelchairs or mobility devices. If needed, bus operators will ask ambulatory riders,

---

(2) Federal Transit Administration. FTA Circular 4702.1B – Title VI Requirements and Guidelines for Federal Transit Administration Recipients (2012), https://www.transit.dot.gov/regulations-and-guidance/fta-circulars/title-vi-requirements-and-guidelines-federal-transit. This circular outlines how agencies must monitor and ensure equitable service across race, color, and national origin. It requires regular analysis of service quality, including capacity constraints and missed trips, to prevent disparate impacts.

[25] https://www.justice.gov/archives/opa/pr/over-3-million-paid-individuals-disability-settlement-greyhound.

[26] https://nypost.com/2025/05/03/us-news/mta-spent-8-years-and-more-than-3m-fighting-disability-advocates-in-court-disgrace/.

[27] https://secondavenuesagas.com/2019/03/12/mta-must-install-elevators-during-all-station-renovations-unless-technically-infeasible-federal-judge-says.

including seniors or those with strollers, to vacate these spots so non-ambulatory passengers can board safely and equitably.

The additional cost stems from the need to provide a replacement service in select instances. The policy states, “Operators are responsible for knowing and abiding by this policy. If an operator is unable to board a passenger in a mobility device for any reason, the operator shall immediately notify VTA’s OCC and follow instructions.”[28]

The OCC then facilitates the need for this replacement service, if applicable. If the next bus to provide service to this passenger (whether on the same route or sharing the trunk route to the passenger’s destination) is not coming within 20 minutes, a field supervisor must make a special trip to transport the passenger. Once the wheelchair securement area is vacant on the original bus, the supervisor must help the passenger board the original bus or drive with the passenger to their destination. If the bus and its passengers wait until the supervisor has reached the location with the alternate transport, even higher time costs are accrued for all passengers.

Therefore, investing in occupancy technology would avoid the operational costs associated with transporting a wheelchair users in this situation. This cost would be calculated as the number of denied boardings that meet this policy, factoring in bus headway thresholds, multiplied by the vehicle operations and staff costs associated with the replacement service:

$$Avoided\ Ops\ Cost = Ct\ of\ denied\ boardings * (Labor\ Cost + \ Vehicle\ Ops\ Cost)$$

Because of the lack of precise data on when such instances occur (the purpose of this Project), below is a preliminary attempt to quantify this avoided cost. Stage 2 would better estimate the cost savings of this benefit.

Table 4-11 lists the number of denied boarding complaints from wheelchair users by year. These denied boardings can occur for various reasons, whether related to lack of space or otherwise, as discussed in Section 0*,*

Passenger Complaints. As a starting point, this section uses the denied boarding count as a base number, of which denied boardings are just a subset (perhaps 25%).

---

[28] https://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/ctma_050919_ppt.pdf. p21.

Table 4-11. Evolution of Denied Boarding Complaints ('Disabled' = 'TRUE')

Year	2019	2020	2021	2022	2023	2024
Complaint Count	46	35	34	36	35	21

Table 4-12 lists the vehicle operation costs associated with buses and paratransit vehicles.

Table 4-12. VTA Operations Cost by Mode of Travel

Mode of Travel	Operational Costs Per Vehicle Service Hour (Fiscal Year 2021)	Reference[29]
Bus	$250	p 23
Paratransit	$120	p 58

Table 4-13 lists the labor ranges associated with a bus operator and a field supervisor, which is assumed to be a similar rate to that of a division superintendent.

Table 4-13. VTA Labor Cost Ranges by Staff Type

Staff Type	Hourly Cost Range	Approximate Loaded Cost Range[1]	Reference
Bus Operator	$23.78 to $39.64	$30 to $45	Starting Pay (2022)[2]
Transportation Superintendent	$69.46 to $84.45	$105 to $125	Salary Schedule (2025)[3]

[1] Assuming a loaded factor of about 1.5x based on healthcare, pension, PTO, etc.

[2] https://www.vta.org/blog/vta-board-approves-adjustment-bus-operators-starting-pay.

[3] https://www.vta.org/sites/default/files/2025-03/salary_schedule.pdf. AFS9 / A158.

If this occupancy data tracking technology helped avoid ten denied boardings for wheelchair users and helped avoid a superintendent needing to drive a paratransit vehicle for 90 minutes from the division to the denied boarding location to the point where the bus had space and back to the division, the avoided cost for this one benefit category could be calculated as follows:

$$Avoided\ Ops\ Cost = Ct\ of\ denied\ boardings * (Labor\ Cost + Vehicle\ Ops\ Cost)$$

[29] June 2024 Audit of VTA: https://mtc.ca.gov/sites/default/files/documents/2024-09/VTA_TDA_Final_Audit_Report_June_2024.pdf.

$$Avoided\ Cost = 10\ occurrences * (1.5hrs) * \left(\frac{\$110}{hr} labor\ + \frac{\$120}{hr} Vehicle\ Ops\right)$$

$$Avoided\ Cost = \$3{,}450$$

This example shows a cost savings of approximately $3,450 for the ten passengers who had to be transported separately by a supervisor. Although these savings are small relative to the operational costs of VTA, they are conservatively avoiding the lost time (and VTA brand damage) of all passengers who had to wait for the superintendent to reach the stop.

Additionally, this benefit category of avoided supplementary pickup cost savings is one that other agencies may wish to assess based on their specific operational circumstances. Although the reputational benefits of helping passengers and operators avoid contentious situations where priority seating areas are occupied are significant, they may be difficult to quantify. These benefits would be considered more closely during Stage 2.

4.4 Stage 2 Considerations

Through Stage 2, the project team would collect data across a larger number of routes, receive occupancies in real-time, and more thoroughly pilot the CCTV-based method for tracking occupancy.

Below are a few cost-related considerations that can provide more visibility on the return on investment in Stage 2:

- **Refining Perceived Benefits:** BCAs are often an iterative process of brainstorming sessions with agency feedback on quantitative assumptions. Stage 2 would revise each of the benefit categories and define assumed values, if not already identified.
- **Scenarios:** Stage 2 would include defining various scenarios to model and compare relative benefits. For example, are the benefits of enabling providing real-time occupancy to passengers worth the costs? This scenario would be used as a platform for discussion, recognizing significant intangible benefits related to customer experience.
- **Fleet-wide Cost Scaling:** How do vendors price hardware and software across 10, 50, or 500 buses?
- **Product Roadmap:** Would new buses come with this technology from the OEMs, or would agencies need to retrofit the buses themselves?

- **Technology Evolution:** Given the rate of change of AI, how can agencies avoid technology obsolescence? If sensors are still functioning at the end of a bus's useful life, can they be repurposed onto a new bus?
- **Agency Staff Cost:** What are the ranges of an agency's staff cost (in terms of time) versus that of vendors?
- **CCTV Costs:** Perhaps the largest unknown is how might the costs of using existing CCTV cameras compare to installing new hardware? Are the benefits of increased precision, future-ready analytics, and synergies with multiple use cases (that is, bike rack occupancy detection or bus lane enforcement) fully achievable?
- **Funding:** What are the potential funding options for such a project?

4.5 Anticipated Impacts (SMART)

To satisfy the performance measurement requirements established in the SMART grant agreement, Table 4-14 provides qualitative descriptions of the anticipated impacts of at-scale implementation in each of the following goal areas.

Table 4-14. Project Alignment to SMART Grant Impact Categories

Impact Category	Description	Project Alignment
Safety and Reliability	Improve the safety of systems for pedestrians, bicyclists, and the broader traveling public. Improve emergency response.	For this Project, safety is not applicable; however, the Project would improve the reliability of transit for bicyclists and wheelchair users by providing real-time, on-board occupancy data.
Accessibility	Improve access to jobs, education, and essential services.	This Project would improve access to transit and accessibility and reliability for wheelchair users and others who require the use of the priority seating areas on transit.
Partnerships	Contribute to economic competitiveness and incentivize private sector investments or partnerships, including technical and financial commitments on the proposed solution. Demonstrate committed leadership and capacity from the applicant, partners, and community.	This Project would promote partnerships with technology vendors, such as CAD/AVL, occupancy sensing, real-time aggregators, software providers, etc.

Impact Category	Description	Project Alignment
Integrations	Improve integration of systems and promote connectivity of infrastructure, connected vehicles, pedestrians, bicyclists, and the broader traveling public.	This Project would improve multimodal transportation connections between the bicyclist and transit networks by identifying where bicyclists use transit to fill gaps in their trips.

As described in Section 3.3*, Performance Measures for Prototype*, this Project meets the requirements of IIJA Public Law 117-58 Sec 25005 D(3)(ii). At-scale implementation (Stage 2 and beyond) would enable agencies to access to greater occupancy data (eventually across all routes), which would help drive planning decisions.

Once the most viable technology pathway is selected (whether new physical sensors or through existing CCTV cameras), VTA would also explore the viability of providing this information to passengers. This network-wide information would improve access to transit service.

4.6 Baseline Data Collection

This Project collected occupancy data, which is shown in the Velolink dashboard and the Clever Devices' vehicle state files. Given the limited data collected through the end of Stage 1, further performance evaluation would be possible in Stage 2 to guide at-scale implementation. For more information, see the Data Management Plan and Section 3.7*, Reporting Capabilities*.

Wheels on the Bus Report

Chapter 5:

Project-wide Challenges and Lessons Learned

5. Project-wide Challenges and Lessons Learned

During Stage 1, the project team encountered several challenges while testing the new sensor technologies, integrating the technology into on-board systems, collecting CCTV footage, and quantifying the benefits of these investments. This section addresses challenges that cut across workstreams on the Project and the lessons learned that would drive the project team's approach for Stage 2.

5.1 Challenges

Many of the challenges encountered during Stage 1 relate to the specific systems that are discussed in prior sections. For more information about specific challenges, see the following sections:

- **Sensor Prototyping:** Section 3.5.6, *Summary of Sensor Implementation*
- **CCTV:** Section 3.6.6, *Challenges Ahead and Considerations*
- **BCA:** Section 4.4, *Stage 2 Considerations*
- **Real-time:** Section 0, *Enablers for Real-time Occupancy*

Broader project-wide challenges include the following:

- **Fully Engaging Project Partners:** As with any industry-first effort, this USDOT-sponsored pilot project requires VTA and Project Partners to take a calculated risk to uncover unknowns for the industry. Project funds enabled vendor compensation for time, parts, and development efforts, some of which were performed pro bono. However, only some partners engaged continuously throughout Stage 1, with high responsiveness and interest in validating products to help the industry. These successful relationships hinged on clearly aligning the value of the Project with the partner's core missions and roadmap. Going forward, the project team would need to invest more time candidly strategizing upfront with all Project Partners to align on expectations to meet project timelines and objectives (that is, real-time transmission functionality).

- **Hardware Changes:** How the first generation of hardware will compare to later generations is uncertain, and transitioning between these iterations could be simple or it could present challenges. For example, the Sportworks connectors that facilitate signal transmission from the bike rack harness to the Velolink system may evolve. Therefore, it is important to ask, how should the agency plan to scale up while mitigating the risks associated with downstream hardware changes?

- **Hardware Damage During Lifecycle:** The project team identified several buses with pre-installed Sportworks bike racks (without Velolink) that had damaged harnesses. The connectors were also corroded; therefore, these bike racks were deemed nonfunctional. Agencies need to collect asset lifecycle data, such as average age or average mileage, to determine when the equipment should be replaced.

  > Transit agencies need guidance on how to plan for new technology assets – including their age, maintenance, and spare parts. The TCRP can help cover gaps through studies.

  One way to cover this gap is through the Transit Cooperative Research Program (TCRP). TCRP reports compile existing practices, lessons learned, and challenges from transit agencies across the country, especially in areas where formal standards or guidance are lacking. Such reports can inform future research or standards development.[30]

  Through a separate bus automation study, the project team used the TCRP platform to propose a synthesis study on considering 'Automated Driver Assistance Systems as Assets.' That study similarly expressed a need to plan for the lifecycle of new transit technology assets.

- **Installation:** Sportworks and VTA had to collaborate to understand how much power the new sensors required and how to access the required power on the bus. Even with coordination between experts, installation can include unexpected challenges that require additional time when the innovation bus is not in service. Similarly, Q'STRAINT required extra time for wiring the wheelchair securement sensor.

[30] https://www.trb.org/Publications/PubsTCRPSynthesisReports.aspx.

> After testing technology in the yard, the Project Team must also assess whether the sensors work properly during revenue service. If bus operators need to take specific actions to ensure that the signal is reliably transmitted for each passenger, they must be trained accordingly.

- **Operational Verification:** The wheelchair securement device requires that the wheelchair be restrained tightly, which bus operators may not feel comfortable doing. The project team found several examples of loose restraints via CCTV footage, which would result in not detecting these passenger's securement. These ambiguous outcomes highlight the need for on-the-job shadowing or renewed training for bus operators to learn how to use the technology to meet the demands of passengers and VTA. Shadowing the staff who interact with the sensors on an in-revenue route would also help identify potential gaps in how the systems work and, as a result, data reliability.
- **Real-time Data Access:** Another unknown is how to transmit real-time data from each sensor. This Project successfully retrieved location- and timestamped data, but transmitting real-time data is pending for both Sportworks and Clever Devices. Stage 2 would develop this functionality further. For more information about the constraints to accessing and transmitting the real-time data, see Section 6.1.3, *Real-time Occupancy for Passengers*.

5.2 Lessons Learned

This section discusses the lessons learned across all phases of the Project, from technology capabilities to agency processes to on-the-ground implementation.

A central takeaway was the value of cross-functional collaboration across VTA departments. The ability to engage staff with specialized knowledge helped shape a more effective and informed prototyping process. Involving the PDT was especially instrumental in ensuring that the Project addressed both technical and operational realities. The following overarching insights emerged:

- **Retrofit Process:** VTA can efficiently retrofit buses with sensors for bike racks and wheelchair securement devices through the steps described in Section 3.5, *Sensor Implementation*. The installation process benefited greatly from coordination efforts led by VTA's Bus Engineering and Maintenance and PDT members, who helped organize Engineering Technician schedules and yard access. Their insights on bus maintenance and the realities of day-to-day wear and tear added valuable context that helped refine implementation strategies. To support future scaling, a reference guide should be developed to help technicians connect systems quickly and accurately.
- **Cable Routing:** Technicians now know where to pull power from and how to route cables on the coach. Although detailed instruction manuals are beyond the scope of this report, progressive vendors could provide thorough documentation and hands-on training to reduce the learning curve for other agencies.
- **Maintenance:** Though all buses had Apex-3 racks installed, the magnets that enable the sensors to sense occupancy had fallen off many of the buses.[31] Over time, and with exposure to adverse conditions, the magnets fell off because of ineffective adhesion. Although the magnets are not difficult or costly to replace, this unexpected part failure requires extra analysis regarding maintenance and lifecycle costs. Through PDT meetings, VTA's Mechanical Engineer staff provided input highlighting how real-world conditions, including temperature, vibration, and rider interaction, can impact sensor components. For more information about this issue, see Section 3.5.4, *Bus 4403*.
- **Unexpected Delays:** In March 2025, data collection came to a halt for two weeks when the Amalgamated Transit Union Local 265 workers went on strike. This union includes bus operators and maintenance staff. Project timelines must include a margin for such unexpected events.
- **Coordination with Operations:** VTA requested that the test bus be assigned to specific routes. Although not challenging, this coordination is an extra step that could be more complicated at larger divisions. VTA's test bus also operates in regular revenue service, often carrying passengers daily, but VTA had enough buses so that the test bus could be held from service as needed. However, other agencies

[31] These magnets are separate from the Velolink hardware that enables data transmission off the bus. They are used to activate the magnetic reed switches on the bike counter system.

may need to plan for their ability to hold back vehicle(s) for testing as availability numbers fluctuate.

- **Service Planning Insights:** Input from internal stakeholders extended beyond operations and maintenance. For example, staff from VTA's Service Planning department shared perspectives on how real-time occupancy data could be leveraged to better inform planning decisions. Although the data in this pilot project were largely qualitative, future phases should aim to generate more concrete insights that could support route planning.

Wheels on the Bus Report

Chapter 6:

Deployment Readiness

6. Deployment Readiness

6.1 Successful Implementation to Scale

Installing occupancy tracking fleet-wide would benefit both passengers and VTA internal planning. Accurate real-time priority seating and bike rack occupancy information, provided to customers via a mobile app, such as Transit App or a custom website, could help customers make immediate decisions as a bus approaches. Historic occupancy data, including data trends, could help customers plan trips in advance and enable VTA planning to consider high-demand times when planning schedules.

During public engagement, passengers said real-time and historic information could help with trip planning, and bus operators said that this data could improve service by reducing instances of denied boardings and passenger confrontations.

This section focuses on how to take lessons learned from Stage 1 and apply them to a larger set of the fleet. In Stage 2, further data collection and prototyping would be needed.

6.1.1 General Considerations

Transit agencies manage large fleets—VTA alone operates 440 active buses—and with vehicle lifespans ranging from 12 to 18 years, any onboard technology must be thoughtfully designed to permit long-term use. Hardware should be compact, affordable, durable, and easy to install, relying on the bus's existing power supply and requiring minimal maintenance over time. Similarly, back-end systems must be secure, scalable, and cost-effective with low maintenance time to accommodate high data volumes.

For bike rack occupancy, VTA could use the Sportsworks bike racks already installed on the buses. However, during the pilot, the project team discovered that the magnetic sensors on most racks had fallen off. Sportsworks identified the issue and developed new installation specifications to address the problem. To scale to full-fleet, VTA would need to install new sensors on the bike racks, using Sportsworks new specifications.

In contrast, determining the occupancy of priority seating areas presents a more complex challenge and the pilot did not yet identify the best way to measure occupancy. It is still undecided how best to differentiate between passengers entitled to use these areas—individuals with mobility devices—and those who use them when the spaces are otherwise unoccupied. Addressing this issue may require the use of camera-based systems with computer vision and AI capabilities. Policies, training, and customer-facing communications could better clarify who may use shared priority seating and under what circumstances. Alternatively, when procuring future buses, VTA could require dedicated priority seating areas instead of shared areas, potentially making enforcement easier and reducing the need for complex technology solutions.

6.1.2 Data for Service Planning Decisions

Based on the findings from the wheelchair ramp deployment analysis, the Planning and Operations teams could focus on monitoring stops and periods with the highest number of ramp deployments, particularly on Routes 22 and 25, during midday weekday service. These routes offer an ideal environment for piloting and validating new sensors designed to detect wheelchair occupancy in the priority seating area.

Expanding sensor installation across a greater number of buses would allow VTA's Planning and Operations team to consider demand when developing schedules and headways. This granular occupancy data could also facilitate VTA and local agency efforts to evaluate and prioritize the accessibility improvements and bicycle infrastructure at high-deployment stops.

6.1.3 Real-time Occupancy for Passengers

Since its inception, this Project has aimed to provide passengers with real-time occupancy data. The first step to providing this real-time data is testing methods for collecting data through on-board sensors.

Stage 1's core focus was to enable data from on-board sensors and systems. Stage 2 would determine whether and how to provide real-time occupancy information to passengers.

This section provides a roadmap for Stage 2 to consider how to collect and transmit real-time data based on discussions with VTA and real-time software partners.

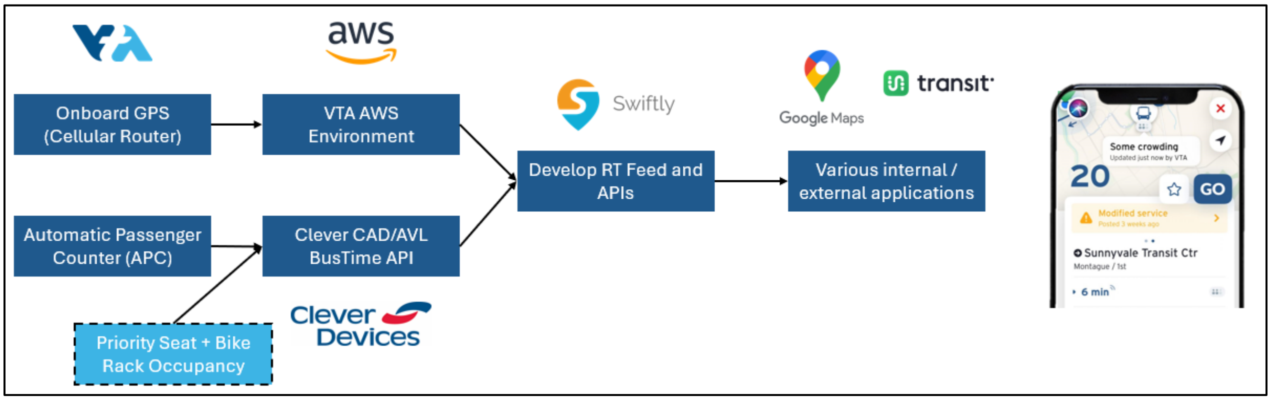
This section covers the following topics:

- Existing Real-time Technology Stack
- Enablers for Real-time Occupancy
- Mobile App Development Trade-offs
- Process for Updating the GTFS-RT

Figure 6-1 shows a representative view of VTA's real-time technology stack.

This section describes how this data pipeline would work and the adjustments that would be needed to share occupancy data with passengers.

Figure 6-1. VTA Existing Real-time Feed Development Process (High-level)



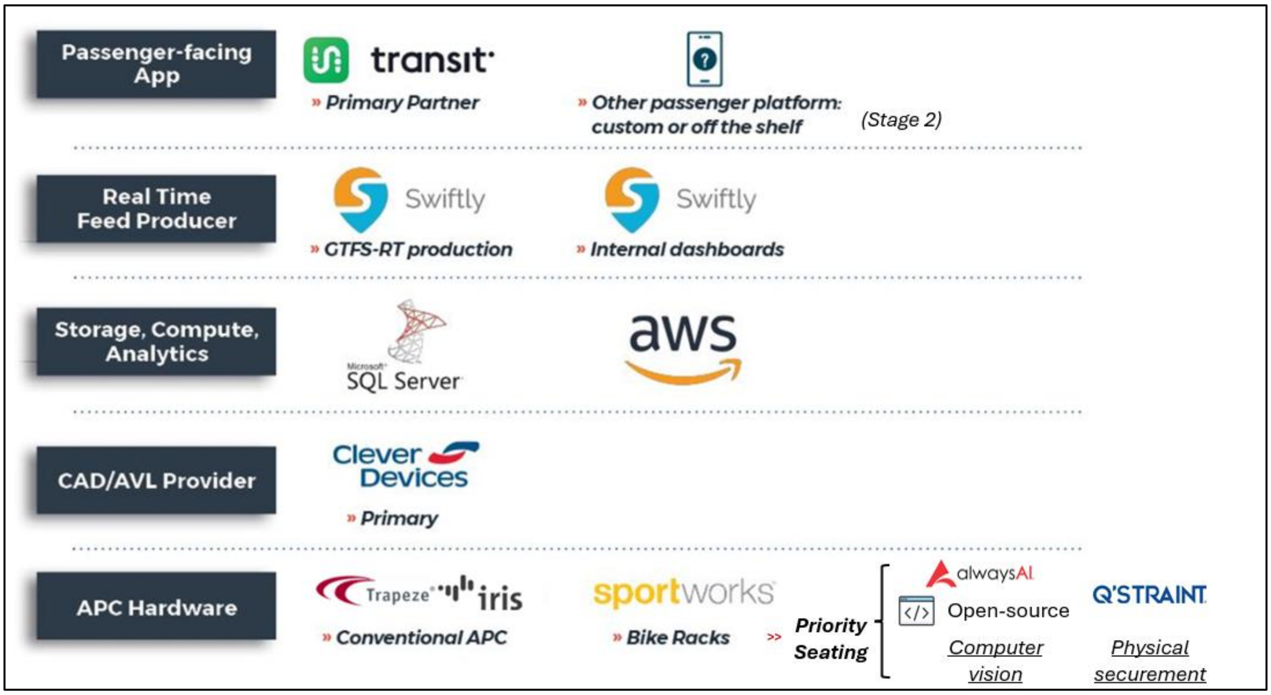
Source: WSP 2025

Existing Real-time Technology Stack

Early on, the project team began understanding VTA's existing real-time technology stack. Figure 6-1 Figure 6-2shows a representative view of key technologies in this stack, from on-board sensors to the existing CAD/AVL provider, and to passengers.

Passengers can see real-time loading information in Transit App through conventional APC data, which serves as the analog for this new occupancy stream. Although the specific real-time architecture of VTA is confidential, VTA would aim to package new occupancy data into a real-time feed. This integration would occur by including the data in Clever Device's BusTime feed, provided from on-board GPS data to Swiftly via AWS. The project team would define the precise data pipeline, including intermediate transformations required, in Stage 2.

Figure 6-2. Real-time Occupancy Technology Stack



Enablers for Real-time Occupancy

A few fundamental enablers are required to provide passengers with real-time occupancy data. These enablers extend across real-time data availability, reliability, and need. Table 6-1. describes these characteristics and the next steps.

Table 6-1. Enablers and Next Steps for Real-time Occupancy Data

Real-Time Enabler	Explanation	**Next Step (Stage 2)**
Data Availability from Source Sensor	Can the on-board technologies piloted in Stage 1 provide data in real-time? These technologies are Sportworks Velolink, Q'STRAINT via Clever Devices, and computer vision with alwaysAI.	Coordination with each vendor and internal VTA research; Sportworks is currently developing their API suite to access occupancy data; the timeline for real-time data from Clever Devices through IVN is currently unknown, and real-time CCTV footage retrieval requires further investigation.
Established Data Pipeline	Building systems to transmit data from source sensors into agency's real-time feed.	Collaborate with VTA IT and Clever Devices' BusTime APIs to develop test data pipeline. This pipeline would treat these new occupancies like existing APC data, integrating this information into the real-time feed.

Real-Time Enabler	Explanation	Next Step (Stage 2)
Industry Consensus	Does the industry agree on the need for providing such information to passengers?	Evaluate the trade-offs between providing this data in a custom app versus Transit App, as discussed in Table 6-2. If working with Transit App, engage with a handful of peer transit agencies about their interest. This consensus would facilitate a GTFS-RT specification update, described in Table 6-3.
Data Reliability	The utility of real-time data hinges on its high reliability, which helps to build passengers' trust in the agency. Is data sufficiently reliable and available at low latency to provide to passengers?	Assess reliability of sensors (validating actual occupancy status against that shown in the data). Establish data quality thresholds, including reliability and latency.
Value to Passengers	(1) Do passengers directly express value in this information (yes for historical data, maybe for real-time data, per stakeholder engagement) and (2) Will this information meaningfully help them? For instance, suppose that historical data shows that only 2% of passengers with "wheels" experience denied boardings. Is enabling real-time passenger information still a worthwhile investment of time? Perhaps prioritizing service planning improvements is better allocation of limited agency resources.	Continue to analyze trends from historical occupancy to quantify how often the capacity for "wheels" cannot meet passenger demand. Given the lead time to enable real-time, cautiously explore next steps in parallel.
Cost-benefit Analysis	Previously, agencies had no direct data on "wheels" occupancy (even historical). Is investing in real-time occupancy technology worth the investment? Or does historical access for internal planning effectively help reduce denied boardings?	Discuss trade-offs as a team, particularly as trends become more apparent (frequency of insufficient capacity). Build a scenario in the BCA model focused on quantifying real-time benefits (Section 4, *Anticipated At-scale Costs and Benefits*).

Mobile App Development Trade-offs

VTA has two options for providing passengers with real-time occupancy data: update the existing real-time arrival tracking applications, such as Transit App or Google Maps, or create a custom app. With Transit App, there is a large existing user base, including VTA customers, a dedicated set of developers, and scalability for other agencies looking to provide this same information. However, TransitApp requires a GTFS-RT specification to display these occupancy values. Changing this specification requires industry consensus, which can make developing a custom app a more efficient pathway to providing passengers with information more quickly and independently. Table 6-**2** compares the trade-offs of using an existing app and developing a new one.

Table **6**-2. Trade-offs of Using the Transit App Versus Developing a Custom Application

Category	Existing App (Transit App)	Custom App Development[1]
User Base	✓ Strong UI/UX with existing customer base.	❌ No existing users; VTA would need to market the new app in addition to the existing Transit App. ❌ Focus group participants strongly preferred displaying occupancy data on existing tools and apps.
Industry Adoptability	✓ Scalable product for other agencies, which is especially significant given its alignment with SMART grant objectives.	🟡 Do not need to demonstrably convince the industry of the need for this development. However, independently developing an application would require duplicative effort for peer agencies with similar interests.
Resource Requirements	✓ Far more cost-effective; Transit App has a large team of industry-recognized full-stack developers.	❌ Higher requirements for prototype, design, build, and maintain the app.
Timeline	🟡 First requires a GTFS-RT specification change, but then depends on the ability to prioritize development against product roadmaps for Transit and Swiftly.	🟡 Potentially faster timeline for a beta version; do not need to convince Transit App of the business case of extending GTFS-RT functionality. However, the project team would need to begin development from scratch (VTA would need to partner with Transit App to provide real-time passenger information).
Flexibility	❌ Restricted to Transit App's development decisions and timeline. Requires close coordination.	✓ Could consider taking input from passengers. ✓ Development could be focused on the VTA use case instead of a generalizable approach across the industry.

Key: ✓ = favorable outcome, 🟡 = mixed benefits, ❌ = unfavorable (less ideal than alternate approach).

[1] During the real-time testing and troubleshooting phase, the project team would likely test the real-time data feeds by transmitting to an internal website (from an AWS S3 feed archiver, for instance). This custom app approach is intended as the long-term solution to provide data to passengers, separate from the exploratory phases.

Process for Updating the GTFS-RT

Table 6-3 describes the process for updating the GTFS-RT specification. The key step for this update is holding an industry vote to approve the specification change, creating an experimental feature. This step would require aligning with a real-time feed producer (for example, Swiftly) and a feed consumer (for example, Transit App).

In preliminary discussions at the beginning of Stage 1, these software providers indicated that a stronger interest across agencies would be needed to justify their investment of development time. Therefore, Stage 2 would require liaising with peer agencies to assess their buy-in.

Table 6-3. Process to Update GTFS-RT Specification for New Occupancies

	Step Name	Description
1	Identify other champion agencies	Meet with other agencies interested in collecting real-time wheelchair and bike rack occupancy data. Define the value proposition. Q'Straint and Sportworks, who can be brought together as initial champions, have heard from their customers that there is a similar desire for this information.
2	Create a GitHub branch and submit a pull request	Add *occupancyStatusBike* and *occupancyStatusPrioritySeating* to GTFS-RT Vehicle Positions
3	Announce on a mailing list	Notify the GTFS community.
4	Discuss and revise the proposal	This step would require a minimum of a 7-day discussion with community feedback.
5	Develop a working implementation	This step would include Swiftly (producer) and Transit App (consumer) attempting to integrate changes.
6	Call for a vote	This step would require a minimum of a 7-day voting period.
7	Vote and approval	This step would require a minimum of three or more *yes* votes and a unanimous consensus.
8	Merge into GTFS-RT	If approved, MobilityData integrates the update.

Real-time data would help passengers more efficiently plan their trips and promote confidence in VTA's service. However, VTA needs to evaluate how to match availability of space for priority seating and bike racks against demand. Historical data is a powerful source for this supply/demand analysis. Either way, by enabling access to occupancy data, this Project has provided a powerful platform to begin exploring how to provide passengers with real-time data.

6.2 Necessary Learning and Knowledge

According to Sportworks, their bike rack hardware and Velolink sensors are designed to last for the lifespan of buses. Because of the novelty of each of the elements piloted, however, further research and pilots are needed to validate their maintenance needs.

Stage 2 would also examine how to effectively transition occupancy tracking technology onto existing fleets (that is, a strategy to minimize operational impacts to installing equipment, perhaps through alignment with preventative bus maintenance schedules). Additionally, Stage 2 would consider potential workforce impacts associated with this technology, building on experience developing a similar workforce analysis for bus yard automation technology.

Wheels on the Bus Report

Chapter 7:

Wrap-up

7. Wrap-up

This Project has successfully identified occupancy sensing technologies, tested feasible options, and collected preliminary data. This report summarizes the community impact, hardware prototyping, CCTV-based computer vision tracking, reporting capabilities, a return-on-investment framework, and how to provide passengers with real-time data.

Although Stage 2 is outlined as a future possibility, this section provides a brief snapshot of the project highlights and next steps.

Deepened Data Access and Reporting Capabilities: Wheelchair ramp deployment data can serve as an effective proxy for priority seating occupancy, providing a reporting framework that can adapt as information is available. Once available, Sportworks APIs would enable data retrieval from Velolink for both priority seating area and bike rack occupancies. Additionally, to enhance analytics, VTA could ask passengers custom questions about their experience bringing “wheels” on the bus through Transit App’s Rate-My-Ride functionality.

Expanded Denied Boarding and Operations Analysis: A key driver for this Project was to reduce denied boardings. Because complaint data suggests that denied boardings are not driven by a lack of space on board, VTA may want to explore a dedicated denied boarding analysis that integrates qualitative interviews and multiple data sources (for example, call center data, Transit App feedback, customer service reports, on-time performance, cut service). Additionally, Stage 2 would consider gathering data on operator-reported denied boardings and exploring incentives to encourage reporting denied boardings.

Insights for Planning: As VTA continues collecting occupancy data, historical data can provide unprecedented insight into geographic, operational, and temporal trends in passenger movements. VTA Service Planners would need to identify the historical data that could be used to benefit passengers. Once validated and analyzed, this data could be trustworthy to provide to passengers.

Fully Pilot CCTV-based Priority Seating Detection: Given the challenges experienced with hardware sensors and integration into CAD/AVL systems, CCTV-based analysis appears to be a promising avenue. Stage 2 requires a more thorough proof of concept (in-house or with a vendor) to fully demonstrate how computer vision can help detect priority seating occupancy. This model would ideally capture different bus topographies, lighting conditions, and types of occupancy (for example, wheelchairs, pushcarts, and strollers). Stage 2 would include refining the process for retrieving CCTV footage, establishing a secure protocol to store and access footage from VTA servers, and tracking accuracy scores as the model improves. Stage 2 modeling would likely include the following characteristics:

- Model two or three bus seat layouts.
- Demonstrate basic object recognition through an AI vendor (wheel agnostic).
- Train an open-source model to recognize different object types (for example, strollers, pushcarts, and wheelchairs).
- Associate origins and destinations of specific people (that is, not just *is_occupied*, but also when that object entered and exited).
- Evaluate the benefit of detecting bike rack usage through a front-facing camera.
- Consider using a second camera view to increase model accuracy.
- Explore the viability of end-to-end, real-time transmission demonstrated with a rudimentary model. This pilot would extend from CCTV footage to real-time data on a test website.

Real-time Integration: As data becomes available, Stage 2 would require working with partners (Sportworks APIs, Clever Devices' vehicle state file, and alwaysAI) to access real-time data. Assuming that denied boardings are caused by a lack of space, the project team would need to determine the interest in leveraging the GTFS-RT specification to provide passengers with data through existing apps (for example, Transit App).

Benefit-cost Analysis: The BCA included in this report provides a framework for evaluating and quantifying the project benefits, while evaluating project costs associated with the different data collection methods.

Stage 2 would include refining cost categories with partners, validating perceived benefits with VTA, and building multiple scenarios (for example, historic data-only return on investment). Additionally, the BCA's next iteration would provide standard metrics, such as break-even year, internal rate of return, and benefit-cost ratio. This industry-first model would help agencies evaluate the value of investing in priority seating areas and bike rack occupancy tracking for their unique passenger bases and operating environments.

Wrap Up

This Project is the first of its kind; it marks a critical first step toward making transit more visible, accessible, and responsive to passenger needs. Stage 2 would focus on transforming these preliminary findings into real-time, scalable technologies with actionable trend analysis. Industry-leading projects like these, possible only through dedicated grant funding, help to empower passengers with greater information.