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Chapter 1. Introduction

This Operational Concept describes the development of subsequent phases of the Smart Columbus Connected Electric Autonomous Vehicle (CEAV) project. The purpose of this document is to summarize a high-level view of the system to be deployed. This document is not intended to fulfill the purpose of a more traditional Concept of Operations or other standard systems engineering documentation. Rather, it is intended to provide a quick reference for project stakeholders to ensure a consistent understanding of project needs, process framework, and other system attributes. This document contains the following sections:

- **Section 1** provides an overview of the document and of the system to be deployed.
- **Section 2** describes the proposed system and the systems that support it.
- **Section 3** outlines the impacts the system will have on stakeholders.
- **Section 4** explains how the system will be monitored and evaluated.
- **Section 5** presents the requirements of the system from different perspectives.

1.1. **CONTEXT, BACKGROUND, AND SCOPE**

In June 2016, the City of Columbus, Ohio won the United States Department of Transportation (USDOT) Smart City Challenge. Columbus intends to define what it means to be a “Smart City” and serve as a model for other cities wishing to fully integrate innovative technologies, such as automated and connected vehicles into the transportation network. Columbus is acting as a laboratory for Intelligent Transportation Systems (ITS), and it is disseminating lessons learned and best practices to cities across the United States in an effort known as Smart Columbus. The goal of the Smart Columbus project is to connect people by creating opportunity for city residents to better access jobs and services while improving the overall safety and efficiency of the transportation network.

Smart Columbus aims to deploy and evaluate automated shuttles against a series of use cases in a series of pilots commissioned by the City of Columbus, the Ohio State University (OSU), the Columbus Partnership, the Ohio Department of Transportation (ODOT) through its DriveOhio initiative, and coordinated with the Central Ohio Transit Authority (COTA). The proposed technology solution involves vehicles that are Level 4 automated, as defined in SAEJ30161, electric, and connected, serving the public on short trips where other modes are not presently available or convenient. Operations of the fleet are expected to be similar to that of a traditional transit service, with pre-determined routes and signed stops along the routes for passengers to board and alight. The success of this project will be looked at as a guide for potential deployment of future automated vehicle (AV) routes in other parts of Columbus and elsewhere by verifying their ability to perform as intended and providing feasibility for their use in similar environments. The following context diagram provides an overview of the CEAV project and the systems that support this service.

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1 SAE International. J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, revised June 2018, [https://www.sae.org/standards/content/j3016_201806/](https://www.sae.org/standards/content/j3016_201806/).
Chapter 1. Introduction

Integration with the Smart Columbus Operating System (Operating System) is central to Smart Columbus’ vision for facilitating Mobility as a Service (MaaS) and other Smart City applications. The Operating System is a cloud-based, dynamic, governed data delivery platform that is at the heart of Smart Columbus. It is designed to ingest and disseminate data from external systems in which components of other applications will reside in the Operating System as loosely coupled services. The Operating System also serves as the source for real-time operational data and archived historical data from a combination of data storage sources for use by the City of Columbus and third-party applications and developers. The Operating System is the data platform environment that integrates data and data services from multiple sources, including the planned Smart Columbus projects, traditional transportation data, and data from other community partners. The Operating System embodies open-data and open-source concepts to enable better decision-making and problem solving for all users to support a replicable, extensible, sustainable platform.

As it relates to AVs, Smart Columbus has a multi-phase vision for enabling integration with the Operating System. For the first phase, it is expected that a CEAV System Operator will, in addition to its own services, provide General Transit Feed Specification (GTFS) and GTFS Realtime (GTFS-RT) data as well as Automatic Vehicle Location (AVL) data to the Operating System to be made available for other applications. Further, the AVs should allow for capture and archive of onboard sensor data, as well as any incident data.
including event logs. The intention is to eventually include fleet management platforms for all Smart Columbus transportation providers in the Operating System, but initially it will be sufficient for output feeds such as GTFS, GTFS-RT, and AVL to be made available for other applications to use outside of Smart Columbus, and in parallel, routing data to be shared with the Operating System itself. Data needs are described in further detail in Section 5.2.

1.2. GOALS AND OBJECTIVES

The Smart Columbus team is interested in deploying CEAV technology to evaluate the ability of this technology and associated vehicles to enhance the mobility of residents and visitors, to operate on public roadways in Ohio, and to satisfy the specific operating purposes for which each service is intended. Further, the team is interested in better understanding the infrastructure required to implement and support the operation of this technology, the approach to public adoption, the types and value of data produced, the associated cost, and the benefits derived from the use of AVs. To minimize risk and to provide the best opportunity for understanding these factors, it is desired to procure turnkey solutions from vendors responsible for deploying, operating and maintaining the services. Vehicle performance will be recorded, such as time in service, miles traveled, ridership, high-accuracy positioning, speed, battery usage, number of and reasons for disengagements, hard braking, evasive maneuvers, and more. From a program perspective, the data collected by the CEAV will be the primary focus and positioned as a user story in the Operating System, which will provide information, lessons learned, and best management practices to benefit the national community.

The CEAV deployments will benefit the region by demonstrating the potential of this emerging technology to local stakeholders and the public, allowing for an educational experience while also inspiring quicker adoption of future innovations. More broadly, results of this project will be used to inform the following overall goals:

- Better connect the community to services through first-mile/last-mile/only-mile connections by providing a convenient and reliable transit option.
- Grow COTA ridership by encouraging a modal shift to public transit by increasing the attractiveness and availability of end to end transit options.
- Validate and ensure that emerging transportation technology solutions provide equitable and accessible transportation.
- Establish a common data exchange interface that is interoperable across various deployment locations, vehicle types, and CEAV System Operators.
- Aid in informing a set of procurement guidelines, including demonstrated vehicle performance and data sharing requirements, for both operational and capital projects.
- Develop a set of AV operational testing and evaluation guidelines to benchmark AVs.
- Develop a methodology for evaluating the operational safety of the system in various deployment settings based on real-time data provided to the Operating System.
- Summarize lessons learned to help identify needs, understand how to garner user acceptance of systems, and study which interfaces work best.
1.3. OVERVIEW OF USERS

The CEAV system is expected to affect and be affected by a variety of types of users. User classes and the groups of people who comprise them are presented in the following table.

Table 1-1: Users and User Classes

<table>
<thead>
<tr>
<th>User Classes</th>
<th>Applicable Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEAV</td>
<td>Vehicles that provide service for the CEAV system</td>
</tr>
<tr>
<td>CEAV Passenger</td>
<td>Area residents, employees, visitors, etc., some of whom have limited mobility and other disabilities</td>
</tr>
<tr>
<td>CEAV System Operator</td>
<td>Transportation operations and management entity</td>
</tr>
<tr>
<td>Operations Staff</td>
<td>Staff hired by the CEAV System Operator to perform tasks for the CEAV that require human assistance, including onboard operators and vehicle maintenance staff</td>
</tr>
<tr>
<td>City Staff</td>
<td>City of Columbus staff, responsible for infrastructure and roadway maintenance (including snow removal and landscaping)</td>
</tr>
<tr>
<td>City Data Users</td>
<td>City of Columbus users, including Department of Technology (DoT) and Department of Public Service (DPS) employees</td>
</tr>
<tr>
<td>3rd Party Data Users</td>
<td>Public agencies, private application developers, researchers, and other public and private entities</td>
</tr>
</tbody>
</table>

Source: City of Columbus

Other involved personnel who are not direct users of the CEAVs but will interact with the CEAV system are included in Table 1-2. These groups are different types of other roadway users, and will interface with the CEAVs on the public roadways on which they are deployed. The CEAVs will need to be capable of safely interacting with all of these types of other roadway users.
Table 1-2: Other Involved Personnel

<table>
<thead>
<tr>
<th>Class</th>
<th>Applicable Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Vehicle Operators</td>
<td>Area residents, employees, visitors, etc.</td>
</tr>
<tr>
<td>Vulnerable Road Users (VRUs) – bicycles, scooters, pedestrians, etc.</td>
<td>Area residents, employees, visitors, etc.</td>
</tr>
<tr>
<td>Emergency Vehicle Operators</td>
<td>Police/ambulance/fire</td>
</tr>
<tr>
<td>First Responders</td>
<td>Police/ambulance/fire responding to incident involving a CEAV</td>
</tr>
</tbody>
</table>

Source: City of Columbus

1.4. PROCESS OUTLINE

The City of Columbus is working in collaboration with other local partners, including ODOT, DriveOhio, OSU, and the Columbus Partnership to plan, implement, and evaluate this project. Each project partner’s roles and responsibilities include:

- **City of Columbus:** The City manages the Smart Columbus Program, a large and diverse transportation technology deployment and data project, in a way that ensures successful implementation and builds sustainable solutions. The City will be the contract holder for one of the deployments and provide support services and facilitate the data exchange through the Smart Columbus Operating System.

- **ODOT:** As the state DOT, ODOT is a key Smart Columbus partner coordinating data management and availability, managing transportation policy developments, and assisting in the transferability and portability of the Smart Columbus Program to other Ohio cities and regions.

- **DriveOhio:** This statewide initiative is the single point of contact to more quickly and efficiently access the needed resources for smart mobility projects. It serves as the hub for all things automated and connected in the State of Ohio. DriveOhio is the contract holder for the first deployment around the Scioto Mile.

- **Columbus Partnership:** This non-profit, membership-based Chief Executive Officer (CEO) organization represents 65 of Columbus’ leading businesses and institutions. The Columbus Partnership is the proxy for key private sector engagement on implementation of the Smart Columbus Program, as well as a significant funder for the first deployment around the Scioto Mile.

- **OSU:** This university partner provides research and organizational support to the Smart Columbus Program, including through the Transportation Research Center and the Center for Automotive Research. It is providing research support for this project. OSU may be a contract holder for a deployment within the Smart Columbus portfolio in the future.

- **COTA:** The local transit agency provides high-frequency transit service near the potential AV shuttle service area, allowing for ample transfer opportunities for passengers.

Working with these partners and leveraging a public-private partnership model allows for the generation of various use cases, which will result in the deployment of CEAVs in various environments across Columbus, such as in a downtown setting, in a neighborhood, or on a university or corporate campus.
These entities intend to jointly issue requests for proposals (RFP) for CEAVs in various settings aimed at solving various community mobility challenges. The first RFP was issued by ODOT, supported by a memorandum of agreement (MOA) with other project partners. The second RFP was supported by the release first of a request for information (RFI). The RFI was released in order to better understand current CEAV capabilities, solicit input on potential routes and route characteristics, and be able to propose a system that is feasible, attractive, and appropriately challenging for potential vehicle vendors, CEAV System Operators, and other project partners. The schedule for these releases is included in Table 1-3.

Table 1-3: High-level Project Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFP#1 released</td>
<td>July 2, 2018</td>
</tr>
<tr>
<td>Vehicle delivery for RFP#1</td>
<td>September 2018</td>
</tr>
<tr>
<td>RFI released</td>
<td>October 11, 2018</td>
</tr>
<tr>
<td>RFP#2 released</td>
<td>January 17, 2019</td>
</tr>
<tr>
<td>Expected vehicle delivery for RFP#2</td>
<td>September 2019</td>
</tr>
</tbody>
</table>

Source: City of Columbus

Partnering with private, academic, and public-sector partners presents the best opportunity to mitigate the risks to the program and ensure successful deployment. Additionally, it presents the best opportunity for community learning and addressing challenges faced by those seeking to deploy CEAV technology. Safety, interoperability, and user acceptance will continue to be challenges faced by cities and organizations seeking to deploy CEAV technology, and lessons learned by this process will be able to help provide guidance in navigating these challenges.
Chapter 2. System Concept

The use of connected and automated shuttles has been widely proposed as a solution to the first-mile/last-mile/only-mile problem. The City of Columbus intends to address, investigate, and propose solutions to the social and technical challenges currently associated with the use of CEAV technology for safer and more efficient access to jobs and services in a “smart city”.

Social challenges that will be explored in this project include:

- How to gradually introduce and expand a CEAV solution for best results
- How to develop and improve user acceptance and user benefits of AVs
- How to integrate a new transportation system into the rest of the transportation network
- How to increase user perception of safety and reliability of AVs, in particular their use to supplement transit

Technical challenges that will be focused on in this project include:

- Determining how to strategically deploy AVs to improve overall mobility
- Resolving challenges with AVs operating in mixed traffic on urban roads
- Developing solutions to help automated shuttles navigate right of way problems at intersections and elsewhere along the roadway
- Ensuring vulnerable road user safety for interactions with AVs
- Exploring all-weather operation of CEAV technology
- Analyzing latency and high network traffic problems in connectivity through communications with other road users and infrastructure and to the data management hub
- Handling uncertainty due to unpredictable operation of non-automated vehicles, other road users, and environmental conditions

While all items in these lists are important and while the lists could easily be extended, the most important technical problem blocking the deployment of CEAVs in a smart city to enhance mobility is that no certification, testing, and rating systems for safe pre-deployment evaluation methods for these shuttles currently exist. This forces city officials and AV developers to rely on public road testing for the determination and solution of technical challenges like the ones above. This project intends to introduce and help develop holistic tools that will enable a priori determination and solution of connected and automated mobility technical challenges including the actual route and other vehicles and mobility improvements. This will be followed by proof-of-concept experimental work and pilot deployments to demonstrate that connected and automated mobility can be used to improve first-mile/last-mile/only-mile access in a smart city. This research will be supported by project partners, including OSU.

2.1. ROUTES AND POTENTIAL USE CASES

Initially starting with 14 route ideas in various settings for the City-led route that narrowed down to four potential routes and use cases that were refined with stakeholder and industry feedback, Figure 2-1 presents the route where a CEAV service was determined to best enhance access to transportation and help fill a local need in Columbus within current technology constraints. This route has been discussed with stakeholder groups, and engagement is ongoing. This and the other potential routes were developed and created with the following localized goals:
- Connecting the community to jobs and services, including
  - Community centers
  - Opportunity centers
  - Food sources
  - Support services
  - Smart Mobility Hubs
- Improving safety and mobility of travelers by mitigating first-mile/last-mile/only-mile challenges
- Encouraging transit use by expanding locations served and implementing efficient schedules and integrated solutions
- Reducing traffic congestion and greenhouse gas (GhG) emission in the region

*Figure 2-1: St. Stephen’s to Linden Transit Center Route*

The route chosen travels between St. Stephen’s Community Center and Linden Transit Center, both of which are designated as Smart Mobility Hubs within the Smart Columbus project portfolio. These Hubs will provide access to mobility options at chosen areas of community focus, such as transit stops, libraries, and community centers to improve mobility for the surrounding area. Hubs may include features such as real-time information displays; USB charging points; embedded touch screen displays at kiosks with access to
trip planning, emergency calling and other applications; and multimodal resources including bike-share racks and car-share parking. The goal of this route is to connect the community center with the CMAX high-frequency bus rapid transit line as well as the neighboring community.

The segment in blue is an alternate route that provides closer service to Cleveland Avenue, a road with high frequency COTA service. The purpose of this alternate is to provide passengers traveling to and from St. Stephen’s somewhere north of the map area on a COTA route with a better connection. However, traffic operations near Cleveland Avenue may introduce additional complexity to the route. Whether this alternative is pursued (in one or both directions of the route) will depend on collaborative discussions between the vehicle vendor and the Smart Columbus team.

### 2.2. MODES OF OPERATION

Modes of operation establish the “what, where, when, why, and who” of the operational condition of a system. The modes of operation specifically for the new CEAV system are as follows.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode 1: Normal Operating Conditions</strong></td>
<td>System is operating as designed. All CEAVs in the fleet are operating on their routes as designed. The CEAVs have the charge available to complete their operations. When scheduled charging does occur, a CEAV returns to the appropriate location and safely obtains the needed charge. When daily operations are completed, all CEAVs are returned to their designated secure storage location after allowing all onboard passengers to alight at their desired stop. If severe weather or another event occurs but the CEAVs are safely taken out of operation before any safety incidents can occur, the system is considered to be operating as intended despite the transit service no longer being operational. CEAV passengers can communicate with the CEAV System Operator for questions and comments by speaking directly with Operations Staff (who will be stationed on CEAVs and possibly also at stops, especially during initial operations) or by using an onboard interface. Operators are on board each vehicle, monitoring operations and stepping in when necessary.</td>
</tr>
</tbody>
</table>
## Chapter 2. System Concept

### Mode 2: Failure/Degraded Conditions

**Definition**

Everyday operations or a specific incident have caused conditions to degrade from the operational state. Degraded conditions include traffic causing the transit service to be behind schedule, high demand causing the CEAV to be at capacity, or a CEAV running out of charge unexpectedly and needing to return to a charging station immediately. This condition also includes a system component, such as an automatic charging capability, not working as designed and the system needing to revert into a fallback condition, in this case manual charging. The degraded mode also includes passenger safety issues that have caused a passenger alert to be called to the CEAV System Operator, or the CEAV System Operator otherwise being alerted that the CEAV needs additional monitoring or for Operations Staff to step in. Severe weather conditions that impact the safety of the roadway are also included if the CEAV is not removed at the point conditions reach an unsafe state outside the scope of the CEAV’s safe operating conditions.

A failure condition occurs if the CEAV is not able to make it to a charging station before losing charge, if the CEAV has an interaction with a public safety official who believes it is operating in an unsafe manner, if there is a CEAV malfunction that could cause additional issues, or if a collision or other incident has occurred. In these cases, Operations Staff will need to be involved in order for the CEAV to return to a degraded or operational state.

### Mode 3: Maintenance Conditions

**Definition**

The CEAVs will be regularly checked for any issues. If an issue is detected during routine maintenance, preventative maintenance is scheduled, or an emergency breakdown occurs, the CEAV will be taken out of service and repaired by the appropriately trained entity. If operations are ongoing and a spare CEAV is usually held during operations, this CEAV undergoing maintenance will become the spare and service will continue as regularly scheduled. Otherwise, partial service will be provided (i.e., at higher headway) until the vehicle in maintenance can be returned back to service.

### Operational Policies and Constraints

There are various policies and procedures governing the use of automated vehicles in the state of Ohio and the United States as a whole. These include:

- The Federal Automated Vehicles Policy, published by the USDOT and the National Highway Traffic Safety Administration (NHTSA) in September 2016 and updated (as Automated Driving Systems (ADS): A Vision for Safety 2.0) in September 2017 and (as Preparing for the Future of Transportation: Automated Vehicles 3.0) in October 2018, which provides guidance for the developing federal approach to automated vehicle performance specifications, the roles delegated to states, and current and proposed regulatory tools to maintain safety in this new transportation environment while not restricting technological innovation.
• The Federal House of Representatives passed a bill out of committee in 2018 that would have allowed automated vehicle testing for up to 100,000 vehicles in any state and would have overridden state laws. However, the Senate did not pass any similar legislation in 2018, so the bill did not become law. New legislation will need to be passed by the new Congress in 2019.
• Federal Motor Vehicle Safety Standards (FMVSS), also developed by NHTSA, continue to regulate features required of vehicles operated on public roads, in categories such as crash avoidance, crashworthiness, and post-crash survivability.
• ODOT is in the process of developing its approach to AV implementation and, in May 2018, then-Governor Kasich signed Executive Order 2018-04K to establish guidelines for testing AVs in the state. Each vehicle must have a designated operator onboard to monitor the vehicles at all times.

CEAV technologies are an emerging field, and in many cases, existing regulations have not kept pace with the growing capabilities of available products, or have been kept intentionally strict to minimize risk while new advances are tested and added competences are demonstrated. Because of this, it may be necessary to modify and/or customize the procured CEAVs in order to comply with regulations, by, for example, installing a steering wheel and brakes for a human to be able to take control, even if the CEAV is controlling itself for most, if not all, operations and is already equipped with an alternate means of human override, such as a joystick, tablet, or other electronic controller. These existing regulations and any potential changes or opportunities for exemptions will continue to be monitored, as it is possible that other solutions may become available within the planning horizon of the CEAV project. Therefore, the scope of the CEAV project may need to be adjusted based on the regulatory environment at the time of deployment, as well as advancing vehicle capabilities.

The CEAVs will be traveling on roads with mixed-traffic, and even in cases where the roads are closed for testing, the vehicles will need to be able to respond to traditional regulatory signs and signals. Regulatory signs and signals are currently produced for human operators, with regulations and standards on aspects such as the size and color of the text, but a CEAV may be able to understand a barcode or other symbol better than text, or may not even need a physical sign at all, especially if it is traveling on the same route every day and this information has been programmed in. However, it will be essential to maintain these fail-safe options of regulatory sign detection in the event of outages, weak signals, or traditional human vehicle operators who may be unfamiliar with the new technology. The CEAVs should have the ability to communicate with other vehicles in Smart Columbus’s Connected Vehicle Environment using Dedicated Short Range Communications (DSRC).

Because the CEAVs are intended to be operated as a public transit service, this system will also need to operate in compliance with US laws and regulations on public transit. Mandatory compliance with these rules is generally determined by funding source and operating entity, but even if the CEAV system is not required to comply, it should still operate in line with best practices in the industry. This includes meeting Buy America requirements, complying with the Americans with Disabilities Act of 1990 (ADA), integrating universal design and inclusive information and communication technology, and ensuring an equitable service that does not benefit one group at the expense of another (including, for example, a Title VI analysis to determine service and fare equity, if applicable).

However, trade-offs may be necessary when striving to comply with at times contradictory regulations in this quickly evolving space. For example, the intent of this project is to meet the Buy America and ADA requirements as well as comply with FMVSS. However, the vehicle class desired, one which meets SAE Level 4 of automation and has space for a wheelchair, among other features, typically does not have standard driving amenities, such as steering wheels, mirrors, and pedals due to having been designed from

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2 The Executive Order can be found here: [http://governor.ohio.gov/Portals/0/21%21%21EO%202018-04K%20%28Signed%205_18%29.pdf](http://governor.ohio.gov/Portals/0/21%21%21EO%202018-04K%20%28Signed%205_18%29.pdf).
the ground up as an AV. There is an exemption process to get such a vehicle approved to operate on public roadways, however, such an exemption to the FMVSSS cannot be granted for domestically produced vehicles that meet this class, only vehicles that are imported. While most companies that are importing vehicles have set up operations in America, they are currently only managing deployments, and plans to manufacture vehicles that can be used domestically seem to have been put on hold until additional guidance is provided. Likewise, there are Level 4 automated vehicles of a smaller size (modified existing vehicles) that comply with both Buy America and FMVSSS, but many are not ADA accessible.

It is the CEAV System Operator’s responsibility to attain all licenses and permits to deploy the vehicles and certify the operators. It is anticipated that the Offeror will need to apply for a State of Ohio Autonomous Vehicle Operations Permit, Bureau of Motor Vehicles (BMV) vehicle registration and licensing, either a City of Columbus Micro Transit Operator – Vehicle for Hire Owner and Vehicle for Hire Driver or a Public Utilities Commission of Ohio (PUCO) Commercial Motor Vehicle permit, and City of Columbus (or relevant jurisdiction/entity) attachment permit if pole mounted equipment is required for operation.

2.4. SUPPORT ENVIRONMENT

The CEAV project is expected to be supported by an expansion in the responsibilities of certain stakeholders and the enthusiastic support of all project partners. In particular, additional support responsibilities will primarily be the responsibility of infrastructure owner/operators and the CEAV System Operator.

The City of Columbus has supported the development of a CEAV system in Columbus since this project’s conception. Its input and ongoing support, particularly during the development of the routes, will be essential to ensuring the service fulfills project goals and is responsive to employee, resident, and visitor needs and wants in the deployment areas. Other project partners should expect similar responsibilities, particularly if they are the owner/operators of infrastructure in a deployment area.

A transportation operations and management entity will be responsible for CEAV operations and management; this entity is referred to as the CEAV System Operator. The entire CEAV system will be procured as a turnkey solution, and not assembled by the project team beyond specifying the deployment constraints and providing some customizable features such as the type of branding on the exterior and interior of the CEAVs. Thus, the identification and responsibilities of the CEAV System Operator will be specified in any procurement language and included in any eventual contracts. Maintenance will also be contracted out in the same contract as the lease and operations of the CEAVs during the pilot period so that the solution is fully turnkey. The CEAV System Operator will be responsible for ensuring the service is operating as designed and that any potential issues are communicated before a potential incident may occur. The CEAV System Operator will also be responsible for ensuring that passengers are aware of the service and can use it effectively, by coordinating communications and outreach, including for travelers with disabilities. Infrastructure maintenance will be the responsibility of the City of Columbus, but all other maintenance will be the responsibility of the CEAV System Operator. Exact roles and responsibilities will be spelled out in procurement documents and any eventual contracts.

The CEAV System Operator will be responsible for identifying and obtaining a maintenance, storage, and electric vehicle charging facility in close proximity to the service route. The exact facility location will be agreed upon prior to vehicle delivery. This facility shall accommodate access that supports the full hours of operation of the service. The CEAV System Operator is responsible for transporting the vehicles to and from the route and this facility. Operating the vehicles in automated or manual mode for this task is acceptable, and regularly towing the vehicles is not desirable.
2.5. PRODUCT VISION AND ROADMAP

The product vision is a turnkey CEAV service solution, including responsibility for providing, deploying, operating, and maintaining the service. The CEAV System Operator must:

- Be able to collect data, provide this data to the Operating System, and generate reports as to the operation of the vehicles on a regular basis
- Have a way to interact with the people using the service and determine their reaction to the technology, through survey or other method
- Have a demonstrated track record of deploying and operating a CEAV service in a mixed traffic environment, utilizing vehicle capabilities similar to the proposed service

A Request for Information (RFI) was released in the fall of 2018. The objective of this RFI was to better understand current CEAV capabilities and not to make a vendor selection. The input received was used to better inform the procurement and the abilities of the vehicles to perform on some identified routes in the City. Current understanding of CEAVs is summarized in this section but is expected to continue to evolve as additional information from potential project partners is received and the technology advances.

CEAV shuttles are similar in size to existing shuttle-type vehicles, generally with a capacity of about 4 to 15 passengers. The preferred capacity of a vehicle will depend on the use case it is intended to serve. They are intended to be shared and are not individually owned, though they may be owned by a private corporation. They operate at low-speeds, on surface streets rather than freeways, and most are electric, which is efficient at these speeds. Current vehicle capabilities are limited, and selected CEAV System Operators will need to certify that they have visited or watched a posted video of the site during procurement, and plan to conduct an official site visit before deployment if selected, in order to ensure the environment is suitable for their vehicle. Some limitations from vendor outreach include:

- Operating speed: Capped at around 25 miles per hour, with a safe operating speed around 15 miles per hour or even lower in some pilots, in part due to the suddenness with which the vehicle stops when it detects an obstacle, and how this can be unsafe for passengers
- Clearance: For the vehicle, its sensors, and some buffer
- Grade: Especially when fully loaded with passengers, electric vehicles may struggle climbing a hill compared to vehicles with internal combustion engines or fewer passengers
- Vehicle capabilities: Challenges such as changing lanes and making unprotected left turns have not yet been fully resolved, and many vendors are not comfortable operating on routes with these types of obstacles. They also have challenges detecting and responding to signage.
- Environmental obstacles: The vehicles need to be able to consistently obtain a signal for localization purposes, so obstacles such as tall grass and tree cover can be an issue. Additionally, some vehicles need vertical reference points, so long flat stretches can prove challenging as well.
- Level of ADA compliance: Some vehicles are ADA-accessible (they have a ramp and audio/visual features), but not ADA-compliant (which would require a more sophisticated latching system, among other features). A substitute method used in some pilots to date is the deployment of an alternative, fully ADA-complaint vehicle that is not an AV and can be called if needed.

There are many opportunities to deploy CEAV shuttles to supplement or enhance existing transit service. Generally, these vehicles are ideal for short-distance service, where they can be used to tackle the first/last-mile problem. Deployments today have generally also been showcase opportunities, for an agency or organization to show they are innovative and supportive of AV technology. There have also been opportunities for data capture to help guide future developments. For example, a one-year pilot in Las Vegas was sponsored by AAA, who is interested in seeing how people perceive AVs and whether their perceptions may change, if they are directly exposed to the technology. This shuttle was deployed in an
area that attracts many tourists, and approximately half of the passengers have been from outside the state of Nevada, which allows AAA to reach a broader audience and not just the local public. CEAV shuttles can also be used for campus circulation, at a university, employment center, office park, or airport. For example, two shuttles owned by Mcity are being used to supplement the University of Michigan’s existing bus transit service that circulates students and others around campus.3 Deploying these vehicles locally also provides an opportunity to educate the local public on emerging technologies. A transit agency or organization who pilots these technologies early on will be better able to adapt to future innovations, because both internal agency processes and the public will be better prepared for and accepting of AV technology.

There are a growing number of players in the automated transit bus and shuttle space, and new products could come to market at any time as many companies are working behind closed doors to protect their intellectual property and generate a larger splash when they do launch. Non-American vendors have become more familiar with US transit regulations since first introducing their vehicles in the US and have begun installing additional features, such as ramps to comply with the ADA, in newer vehicle models. They have also begun opening manufacturing facilities in the US, to comply with Buy America requirements.

Most vendors offer their vehicles for sale or for lease, and most procurements in the United States so far have been via lease agreements. Vendors have often partnered with traditional transit operating entities to provide a turnkey solution. Vehicle costs vary depending on the supplier and on the features that are included. Lease agreements generally include many operating costs, such as vehicle monitoring and maintenance, while purchase agreements would require O&M costs as well as license and service agreements to be covered in addition to the purchase cost.

2.6. SUSTAINABILITY AND ADAPTABILITY

As CEAV technology continues to advance, many commercial CEAV vendors are striving to deploy more innovative and cutting-edge platforms and business models. It is possible that within the timeline of this project, including during the deployment period, a selected vendor or the industry as a whole will see a major shift, such as:

- Moving to a dynamic operating model, rather than serving stops along a fixed route
- Focusing on smaller capacity vehicles (i.e., personal rapid transit)
- Increased vehicle capabilities, particularly operating at higher speeds and performing better in mixed traffic
- Operating in a different regulatory environment, such as one that places fewer or additional restrictions on the testing of AVs

If any such a change occurs within the timeline of this project, the team may decide to re-evaluate the proposed routes and operating characteristics, potentially modifying a route alignment or switching to a new operating model, such as dynamic service within a specified zone. Overall project goals will remain the same, as will many project specifications such as the need for the service to be accessible to all, including those with mobility challenges, hearing, vision, and cognitive disabilities, and language differences, as well as those who do not own a credit card or smartphone.

3 https://mcity.umich.edu/shuttle/
Chapter 3. Operational and Organizational Impacts

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

The CEAV system will be a small fleet of CEAVs on public roads in mixed traffic. Overall traffic operations on the roads served may be affected. This could lead to an increase in congestion due to the presence of these slow moving CEAVs on the roadway, though if the CEAVs remain on roads with low speed limits they may be able to meet the speed of local traffic flow without any issues. The hesitance of other drivers to interact with AVs may also increase congestion in the short term; however, this is expected to stabilize in the long term. If ridership on the CEAVs is significant, there could be a decrease in local congestion, if these trips would have otherwise been made by private auto.

Because the CEAV system will primarily serve trips of up to around a mile, other short-distance transportation options may see reduced demand. This includes walking and biking or using bike share programs. Localized boarding and alighting behavior on COTA bus routes in the deployment area may be shifted in response to the location of transfer points to the CEAV system and whether they provide a closer service to final destinations.

Modes of operation, particularly during unfavorable weather conditions, will be determined by the capabilities of the CEAV relative to the capabilities of existing transportation options. Certain criteria and processes will need to be established to ensure safe operations of the CEAVs during adverse weather conditions. Service using CEAVs will likely need to be halted during certain conditions that existing transportation options can safely navigate in, which will need to be communicated to passengers and potentially be backed up by another option. The City of Columbus will be responsible for ensuring that any roads along the route are prioritized for road clearing in order to maintain service as long as it is safe.

The implementation of CEAV service is also expected to result in minor organizational impacts for agencies that have agreed to take on additional responsibilities associated with the CEAV system. The CEAV System Operator will be responsible for operating and managing the service. This will include ensuring the CEAVs are operating as planned, safely and on schedule. To do this the CEAV System Operator will need to facilitate a system for monitoring the CEAVs, such as staffing a back office and deploying onboard Operations Staff for passenger questions and onboard monitoring, at least during initial operations. The CEAV System Operator will also be responsible for maintenance, though it may contract this out to an entity with more experience maintaining CEAVs, such as the vehicle manufacturer. Even if maintenance is contracted out, the CEAV System Operator may still need to assist with maintenance by coordinating its service schedule with planned maintenance and ensuring Operations Staff know how to respond to a broken down CEAV, which may be different from how traditional transit providers respond to broken down buses.

The local transit provider, COTA, will feature certain aspects of the CEAV service in its operations, such as showing the service on guide maps and maintaining communication on any schedule changes so the CEAV System Operator can coordinate its schedule with that of COTA (by, for example, providing similar service hours on holidays). The CEAV System Operator will similarly provide information about COTA on its promotional and informational materials, to help facilitate passenger transfers.

Law enforcement and other public safety personnel will need to know how to communicate with the CEAVs in order to maintain safety in the area, and have been engaged in order to discuss how to do so.4

4 Additional safety management strategies are included in Smart Columbus’s Safety Management plan.
Construction workers and managers may need to produce plans to communicate planned work to the CEAV System Operator to minimize the impact of road closures and detours to the service.

Temporary impacts during system development, installation, and testing will be minimal. The routes will be mapped virtually by the chosen CEAV System Operator. Some additional infrastructure investments are expected, including additional signage for new stops (for the benefit of passengers, not the CEAVs), vertical reference points, infrastructure-based cameras, real-time kinematic (RTK) antennae, and roadside units that leverage DSRC. Therefore, there will be limited on-site construction and other local impacts during development. The maintenance and storage garage could be an existing facility, with minor enhancements for security and electric loads, or a temporary structure to meet the needs of the CEAV System Operator.

On-site testing and route mapping will need to occur before deployment. At first, this will be done on closed roads, and could be done at night or during off-peak times. Introducing AVs into mixed traffic operations will be challenging, both for human drivers and for the automated vehicles, as both will have to deal with the unfamiliar and often unpredictable behavior of the other entity. However, this phased deployment approach provides the opportunity to modify the route alignments and other service characteristics if any potential concerns arise during preliminary testing and operations that inform the actual capabilities and safety of the CEAVs.

5 Regular stationary vertical elements, such as streetlights and poles, are used by AVs for localization.
Chapter 4. System Analysis

Routes were selected based on vendor feedback (through the RFI) and assessment of vital characteristics as outlined in the following table.

Table 4-1: Draft Ranking Criteria for Selection of Preferred Route

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Mobility Hub</td>
<td>The route provides a connection to a proposed Smart Mobility Hub as part of the Smart Columbus initiative.</td>
</tr>
<tr>
<td>Food and Service Access</td>
<td>The route connects to food and services needed within a community. The list includes: grocery store, bank, pharmacy, and food bank/pantry.</td>
</tr>
<tr>
<td>Ladders of Opportunity</td>
<td>The route connects residents with job or opportunity centers for enhanced placement access. The list includes an Opportunity Center and Ohio Means Jobs.</td>
</tr>
<tr>
<td>COTA</td>
<td>The route connects to a COTA stop and acts as a FMLM connection to expand the reach of a traveler.</td>
</tr>
<tr>
<td>Healthcare Support</td>
<td>The route connects patients with services that can aid in monitoring and improving their health.</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>The route connects to an opportunity neighborhood for increased mobility.</td>
</tr>
<tr>
<td>Recs and Parks</td>
<td>The route connects to a City recreation center or park.</td>
</tr>
<tr>
<td>Route Navigation</td>
<td>The technology at the time of deployment will allow the route to be traveled.</td>
</tr>
<tr>
<td>Storage</td>
<td>The route provides a nearby facility for storage, maintenance, and charging of vehicles.</td>
</tr>
<tr>
<td>Alignment Considerations</td>
<td>The route satisfies an unmet transportation need rather than duplicating existing COTA service.</td>
</tr>
<tr>
<td>Safety and Accessibility</td>
<td>The route has lighting and sidewalks in the vicinity of anticipated stops.</td>
</tr>
</tbody>
</table>

Source: City of Columbus
Chapter 4. System Analysis

After route selection and deployment, analysis of the deployed system will be guided by the following project objectives and evaluated accordingly. Analysis of progress toward performance measures will be based on the data provided by the CEAV System Operator, as outlined in Section 4.2.

Table 4-2: Project Objectives to Inform Performance Measures

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide convenient, reliable first and last mile transportation</td>
<td>The CEAV will increase the number of convenient, reliable first and last mile trips in the deployment area by providing an automated shuttle service</td>
</tr>
<tr>
<td>Increase COTA ridership</td>
<td>The CEAV will increase COTA ridership by providing an automated shuttle service to assist with first/last mile transportation to/from COTA bus stops</td>
</tr>
</tbody>
</table>

Source: City of Columbus

4.1. EVALUATION CRITERIA FOR ACCEPTANCE

Selected CEAV vendors will be responsible for conducting their normal factory testing prior to delivery of the vehicles to Columbus, and prior to becoming CEAV System Operators. This testing should be performed for the actual vehicles that will be delivered. The CEAV System Operator will be responsible for preparation of a Test Plan and corresponding test procedures, with review and approval by the purchasing team prior to the conduct of the testing. Documentation of the test results and any corrective actions should also be provided with each vehicle. Testing shall include:

<table>
<thead>
<tr>
<th>Performing a low-speed merge</th>
<th>Making appropriate right-of-way decisions at intersections</th>
<th>Providing a safe distance from objects on the side of the road or sharing the lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulling over to the side of the road</td>
<td>Making appropriate right-of-way decisions when interacting with vulnerable road users</td>
<td>Decreasing speed when there is uncertainty regarding which action to take</td>
</tr>
<tr>
<td>Moving out of the travel lane and stopping in order to service stop locations</td>
<td>Detecting and responding to encroaching oncoming vehicles</td>
<td>Detecting and responding to detours and other temporary changes in traffic patterns</td>
</tr>
<tr>
<td>Performing car following when approaching intersections</td>
<td>Detecting stopped vehicles in their path</td>
<td>Operating in rain, fog, and light snow conditions not deemed a weather emergency</td>
</tr>
<tr>
<td>Performing car following in stop and go traffic conditions</td>
<td>Passing stopped vehicles when safe</td>
<td>Entering and emerging from a stop-controlled traffic circle</td>
</tr>
<tr>
<td>Navigating signalized intersections</td>
<td>Detecting and responding to static obstacles</td>
<td>Crossing intersections with traffic speed limits up to 35 mph</td>
</tr>
</tbody>
</table>
Navigating unsignalized intersections | Detecting and responding to moving obstacles | Changing lanes (both left and right lane change)
--- | --- | ---
Performing left and right turns | Interactions with emergency vehicles | Deploying a wheelchair accessible ramp
Making appropriate right-of-way decisions when merging from a transit stop | Detecting and responding to vulnerable road users in or approaching the vehicle’s projected travel path, including at intersections and crosswalks

In addition, prior to each vehicle delivery, the CEAV System Operator will meet with City of Columbus emergency services to provide background and operating information on the vehicles, as well as to participate in a tabletop exercise.

For each deployment, upon the delivery of the vehicles and completion of initial site and vehicle setup, the CEAV System Operator will conduct preliminary acceptance tests, with the purchasing team as witnesses, using the planned routes but in a controlled manner (i.e., necessary road closures, off-peak hours) to ensure component and system verification. At a minimum, the testing activities will include:

- Everyday operations on the route, demonstrating lane adherence, turning, stopping and starting, and safe reactions to situations the vehicle happens to encounter
- Service of the passenger stops (including pulling over, opening and closing doors, and merging back onto the route)
- Operations in changing roadway/weather conditions (if present)
- Operations in peak and off-peak traffic

Upon successful testing and demonstration of the vehicles in this manner, the CEAV System Operator will be permitted to proceed to full operational testing, otherwise known as shakedown, for purposes of data collection and demonstrated ability to operate as desired. During this phase, Operating Staff will be required to be onboard each vehicle, and the vehicles will travel on the planned routes and schedule, but without taking on passengers. Staff from Smart Columbus or as designated by Smart Columbus or the Selected Offeror will be permitted to ride the vehicle during this period and could simulate passenger boardings and alightings.

Upon completion of the operational testing period, the CEAV System Operator will again prepare and conduct a final acceptance test and Test Report suitable for delivery. The Test Report will include any corrective actions necessary. The City and its partners will evaluate this report, and if it is accepted, the CEAV System Operator will be permitted to proceed to normal operations complete with passenger service.
4.2. PERFORMANCE AND SYSTEM MONITORING

The CEAV System Operator will report on the vehicle’s operation on a regular basis to be agreed upon in any eventual service contract. This report will include at a minimum:

- The number of riders, broken down by time-of-day and day-of-week, using door Automated Passenger Counter (APC) devices, video for automated passenger counting, or another solution as specified in the proposal, with geospatial information showing the location where riders boarded and alighted
- On-time performance, with actual departure times from the stops and the causes for any deviations
- A record of trip updates and service alerts
- Number of vehicle trips and vehicle miles and hours traveled – including how many miles were driven in automated mode and the duration of each trip
- Battery performance
- Average vehicle speeds along each segment of the route
- Rider satisfaction (using a survey)
- Any disengagements or interventions by an operator

More detailed reports will be required if any incidents occur. This report will include:

- An identification of the vehicle involved
- Whether any people were involved, and how
- The extent of property damage, if any
- A description of the incident that includes whether the vehicle was in automated or manual mode at the time and any contributing factors
- Video footage of the incident (using video-based cameras both inside and outside the vehicle)
- Additional information as requested
Chapter 5. User Requirements

At a high level, the required solution must be safe and accessible, and must satisfy the mobility needs of users. Overall requirements for the users introduced in Section 1.3 are provided in Table 5-1.

Table 5-1: User Requirements

<table>
<thead>
<tr>
<th>User</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEAV</td>
<td>- Needs to be able to transport passengers (stop at designated locations, open and close doors, deploy accessibility equipment, etc.)</td>
</tr>
<tr>
<td></td>
<td>- Needs to have the ability to reasonably comply with local, state, and federal driving laws, regulations, ordinances, licenses, and certifications</td>
</tr>
<tr>
<td></td>
<td>- Needs to have Operations Staff onboard who have the ability to take manual control of the vehicle if deemed necessary and assist those with mobility needs</td>
</tr>
<tr>
<td></td>
<td>- Needs to meet all applicable FMVSS or have approval to operate under an exemption to the FMVSS</td>
</tr>
<tr>
<td></td>
<td>- Needs to comply with all applicable ADA requirements</td>
</tr>
<tr>
<td></td>
<td>- Needs to comply with all applicable Buy America requirements</td>
</tr>
<tr>
<td></td>
<td>- Needs to comply with all applicable requirements of Title VI</td>
</tr>
<tr>
<td></td>
<td>- Needs to meet the USDOT National Highway Traffic Safety Administration (NHTSA) 12-point voluntary safety self-assessment</td>
</tr>
<tr>
<td></td>
<td>- Needs to have enough power to complete planned operations</td>
</tr>
<tr>
<td></td>
<td>- Needs to stop, open doors if safe, and alert the CEAV System Operator when it has detected that there is an issue on board or with the CEAV</td>
</tr>
<tr>
<td></td>
<td>- The CEAVs should implement DSRC to communicate with roadside equipment to receive Signal Phase and Timing (SPaT) and MAP data. A commercial Security Credential Management System (SCMS) will be provided by the City of Columbus for the vehicles to enroll in.</td>
</tr>
<tr>
<td>CEAV Passenger</td>
<td>- Needs to be able to board and alight the CEAV</td>
</tr>
<tr>
<td></td>
<td>- Needs a designated pick-up/drop-off location to, at a minimum, have proper markings</td>
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<tr>
<td></td>
<td>- Needs information on route, schedule, and ideally current vehicle location to be able to make travel decisions and use the service</td>
</tr>
<tr>
<td></td>
<td>- Needs to be able to communicate that the CEAV should make an emergency stop</td>
</tr>
<tr>
<td>User</td>
<td>Requirements</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| CEAV System Operator       | - Needs to be able to program the operating routes into the CEAV, and make any changes as necessary  
- Needs to manage operations and make adjustments as necessary, ensuring the CEAVs are running on schedule  
- Needs to be able to monitor the situation inside and directly outside the CEAV  
- Needs to have access to a maintenance, charging, and storage facility in close proximity to the CEAV route  
- Needs to be able to contact emergency responders and other City agencies when necessary |
| Operations Staff           | - Needs to have knowledge of and the ability to reasonably comply with local, state, and federal driving laws, regulations, ordinances, licenses, and certifications  
- Need to be able to take secure manual control of the CEAV while onboard if necessary and assist those with mobility needs |
| City Data Users            | - Need access to accurate and timely data on the CEAV system                  |
| 3rd Party Data Users       | - Need access to accurate and timely data on the CEAV system                  |

*Source: City of Columbus*

### 5.1. OPERATIONAL/USER REQUIREMENTS

Operational requirements for deployment will include:

- Each deployment shall provide service during the hours of day and days of week with the highest expected demand.
  - Ridership shall be monitored by time-of-day and day-of-week, and it is expected that operating hours will be shifted and/or shortened in order to better accommodate demand, considering vehicle capabilities.
  - Service may be suspended on major holidays as specified in a contract, though service may be continued on some holidays that are expected to see increased demand.
  - Any changes to service shall be communicated to passengers by multiple modes of communication well in advance of the service change. This includes both schedule and route changes (due to roadway construction, expected changes in demand patterns, road closures due to special events, etc.).
- Each service shall meet a headway that allows for “walk-up” service during the hours in which service is provided, so that passengers can arrive at a stop and expect a vehicle to come within a reasonable amount of time rather than having to pre-plan their trip. The expectation is that a headway around 10-12 minutes would be a good goal, with the exact value depending on other operational characteristics.
  - As with operating hours, desired minimum headway may be modified during certain time periods depending on ridership, but is expected to be low enough to continue to provide “walk-up” service to potential passengers.
- Each service shall be accessible to all residents and visitors who desire to use the service. This, at a minimum, includes the provision of an ADA-accessible vehicle by the CEAV System Operator for passengers who need it, though it is highly desired that all vehicles in the fleet be fully accessible.
• A secure, indoor location shall be provided by each CEAV System Operator for overnight storage. This facility shall include access to electric vehicle charging portals.
• Onboard operators ("Operations Staff") shall be properly trained and shall always be onboard a vehicle while it is in operation.
  o Operations Staff shall be employees, contractors, or agents of the company, as specified in Executive Order 2018-04K.
  o CEAV System Operators for early deployments shall engage in the training of local operators to inform later CEAV deployments.
  o It is the City of Columbus’ preference that individuals performing shuttle operations and maintenance be represented by a collective bargaining agreement.
• Any fleet management system(s) used by a CEAV System Operator shall be open architecture to allow for potential future integration with the Smart Columbus Operating System.
• Each deployment shall have Standard Operating Procedures for the CEAVs and Operations Staff.
  o Procedures shall include emergency response protocols.
  o Procedures shall also include weather response protocols. To support this, local weather patterns shall be monitored such that the CEAV System Operator is aware of any approaching severe weather event or other conditions that may impact vehicle operations.
• Project team members shall identify and/or support research opportunities.
• The project team plans to actively engage the community in the operation of the vehicle and monitor their feedback. This will be accomplished through surveys of both riders and non-riders, and possibly other methods.

More specific requirements have been outlined in any RFPs and contracts developed as part of this project, that are specific to each deployment and may be more restrictive than those outlined above.

### 5.2. DATA NEEDS AND INTEGRATION REQUIREMENTS

CEAV System Operators will be required to agree to collect data on ridership, stop departure times, vehicle miles/hours traveled and route-trips served, battery performance, rider satisfaction, and any disengagements or interventions by an operator. Any and all data presented in the following table collected by the CEAV System Operator must be shared with Smart Columbus unless it is deemed proprietary information by the vendor.

#### Table 5-2: Proposed Data Needs

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>Vehicle route and schedule (GTFS)</td>
</tr>
<tr>
<td></td>
<td>Real-time vehicle location information (AVL, GTFS Realtime)</td>
</tr>
<tr>
<td></td>
<td>Trip updates and service alerts</td>
</tr>
<tr>
<td></td>
<td>Ridership (stop-level boardings and alightings)</td>
</tr>
<tr>
<td></td>
<td>Actual stop arrival and departure times</td>
</tr>
<tr>
<td></td>
<td>Vehicles miles traveled</td>
</tr>
<tr>
<td>Data Type</td>
<td>Data</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Vehicle hours traveled (hours the vehicle is in service)</td>
</tr>
<tr>
<td></td>
<td>Number of route-trips served</td>
</tr>
<tr>
<td></td>
<td>Duration of each trip</td>
</tr>
<tr>
<td></td>
<td>Battery usage (such that it can be associated with weather,</td>
</tr>
<tr>
<td></td>
<td>temperature, vehicle load, etc.)</td>
</tr>
<tr>
<td></td>
<td>Average vehicle speeds along each segment of the route</td>
</tr>
<tr>
<td></td>
<td>Count and duration of wheelchair ramp deployments</td>
</tr>
<tr>
<td>Performance</td>
<td>Sensor and other telemetry data</td>
</tr>
<tr>
<td></td>
<td>Navigation variances</td>
</tr>
<tr>
<td></td>
<td>Probe data (nRTK-enabled or similar)</td>
</tr>
<tr>
<td></td>
<td>Mechanical data (vehicle condition)</td>
</tr>
<tr>
<td></td>
<td>Disengagements/interventions by the operator, relative to the</td>
</tr>
<tr>
<td></td>
<td>amount of time spent in automated mode</td>
</tr>
<tr>
<td></td>
<td>Any other logged events (hard stops, evasive maneuvers, unruly</td>
</tr>
<tr>
<td></td>
<td>passenger behavior, etc.)</td>
</tr>
<tr>
<td></td>
<td>Conditions driven in (weather, congestion, etc.)</td>
</tr>
<tr>
<td></td>
<td>Incident reports (Incidents include any collisions, and passenger</td>
</tr>
<tr>
<td></td>
<td>behavior or other situations when an external entity is called</td>
</tr>
<tr>
<td></td>
<td>upon for assistance)</td>
</tr>
<tr>
<td>Communications</td>
<td>Record of operational data exchanged (includes SPaT and MAP</td>
</tr>
<tr>
<td></td>
<td>messages the vehicle receives, BSM it sends, etc.)</td>
</tr>
<tr>
<td>Rider feedback</td>
<td>Rider satisfaction</td>
</tr>
<tr>
<td>(provided by survey</td>
<td>Rider acceptance of the technology</td>
</tr>
<tr>
<td>results, not directly from CEAV</td>
<td></td>
</tr>
<tr>
<td>System Operator)</td>
<td></td>
</tr>
</tbody>
</table>

Source: City of Columbus

Smart Columbus will also define a set of interoperability guidelines for multiple CEAV System Operators to communicate with infrastructure and a central fleet management system to ensure that various systems deployed throughout the city, state, and nation can be deployed interchangeably. To support this need, data which allows for traditional transit services, such as GTFS and GTFS-RT, will be required. Data related to the automated driving activities, including event logs, sensor data, and other telemetry data will also be required.