Phase 1 Enabling Technology Readiness Assessment

Buffalo NY ITS4US Deployment Project

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Final Report — Jan 13, 2022
FHWA-JPO-21-888

COMPLETE TRIP

ITS4US

U.S. Department of Transportation

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Notice

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16. Abstract

The Buffalo NY ITS4US Deployment Project seeks to improve mobility to, from, and within the Buffalo Niagara Medical Campus by deploying new and advanced technologies with a focus on addressing existing mobility and accessibility challenges. Examples of the technologies to be deployed are electric and self-driving shuttles, a trip planning app that is customized for accessible travel, intersections that use tactile and mobile technologies to enable travelers with disabilities to navigate intersections, and Smart Infrastructure to support outdoor and indoor wayfinding. The deployment geography includes the 120-acre Medical Campus and surrounding neighborhoods with a focus on three nearby neighborhoods (Fruit Belt and Masten Park) with underserved populations (low income, vision impaired, deaf or hard of hearing, wheeled mobility device users and older adults).

This document is the Enabling Technology Readiness Assessment (ETRA) which identifies each of the technologies that will be utilized to meet the user needs and system requirements identified within the Concept of Operations (ConOps) and the System Requirements Specification (SyRS).

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ICF	Nov 15, 2021	0.2	Revised version based on comments from USDOT
ICF	Dec 17, 2021	0.3	Secondly revised version based on the second round of comments from USDOT
ICF	Jan 13, 2022	0.4	Final version with edits based on third round of comments from USDOT

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1 Introduction

Buffalo, New York (NY) is one of five sites selected for U.S Department of Transportation (USDOT) Complete Trip - Intelligent Transportation Systems for Underserved Communities (ITS4US) Deployment Program, which seeks to integrate innovative technologies to improve mobility and accessibility. The Buffalo, NY project plans to deploy an integrated set of travel support services and systems within neighborhoods surrounding Buffalo Niagara Medical Campus (BNMC).

This document, the Phase 1 Enabling Technology Readiness Assessment (ETRA), identifies and assesses the matureness of the enabling technologies to be used in the development of an integrated solution for this deployment project. It is important to note that this is a live document and will be updated later in the project—for instance, towards the end of Phase 1 once the System Requirements are known and specified.

1.1 Intended Audience

This document has been written to serve the information needs of multiple and varied audiences. This includes:

- USDOT members: Intelligent Transportation System (ITS) Joint Program Office (JPO), Office of the Secretary (OST), Federal Highway Administration (FHWA), and Federal Transit Administration (FTA).
- The Buffalo ITS4US Team: ICF, NFTA University at Buffalo (UB), BNMC, Open Doors Organization, RSG (Resource Systems Group), and ETCH. The ETRA provides a baseline to engage vendors, developers, and other potential partners in developing the *Partnership and Financial Plan and Deployment Plan.*
- External members: independent evaluators (IE) or interested technology specialists.
- Public sector partners: NY State Department of Transportation, the Niagara Regional Transportation Commission, City of Buffalo, and the Niagara International Transportation Technology Coalition (NITTEC, a coalition of agencies across Western New York and Southern Ontario).
- Other important stakeholders: neighborhood associations, medical, healthcare, community, and human service organizations, and the BNMC Transportation Operations Council.

1.2 Project Background

Buffalo is striving toward a sustainable future at all levels of society, incorporating actions in the community, government, and private entities in the area. Enabling community mobility and access to jobs, healthcare, and services to traditionally underserved populations is the primary motivation for all the regional partners involved in this deployment.

The Complete Trip - ITS4US Deployment Program is an effort led by the ITS-JPO and supported by OST, FHWA, and FTA to identify ways to provide more efficient, affordable, and accessible transportation options for underserved communities that often face greater challenges in accessing essential services. The program aims to solve mobility challenges for all travelers with a specific focus on underserved communities, including people with disabilities, older adults, low-income individuals, rural residents, veterans, and limited English proficiency travelers. This program will enable communities to build local partnerships, develop and deploy integrated and replicable mobility solutions to achieve complete trips for all travelers.

As one of the selected sites, the Buffalo, NY ITS4US deployment concept addresses:

1. **Providing transit access to healthcare and jobs** to underserved residents including persons with disabilities and allowing them to share in the economic development in downtown Buffalo.
2. **Leveraging technology to work in support for accessible transportation**, integrating accessible transportation technology, transit, and connected automation to solve a transportation need.
3. **Developing a scalable model** for considering accessibility and universal design in transportation technology projects.

The Buffalo, NY ITS4US project will be completed in three phases:

- Phase 1- Concept Development.
- Phase 2- Design and Test.
- Phase 3- Operation and Evaluation.

1.3 Scope

The ETRA uses information from all internal documents developed up to this point of the project, namely Tasks 2 through 6, as shown in Figure 1. The ETRA also feeds other key internal documents. As such, the ETRA will be updated periodically and as needed throughout the project to correct any inconsistencies that may arise as other project documents become available and as the concept continues to mature. This document provides detail of how the enabling technologies will address the user needs and requirements through integrated solutions.

Through this ETRA, the Buffalo project team will identify the readiness for deployment of the proposed technologies and how the team plans to manage and address risks. This document also serves as a foundation / starting point for other agencies seeking to deploy similar individual or groups of technologies to achieve Complete Trip goals within their region.

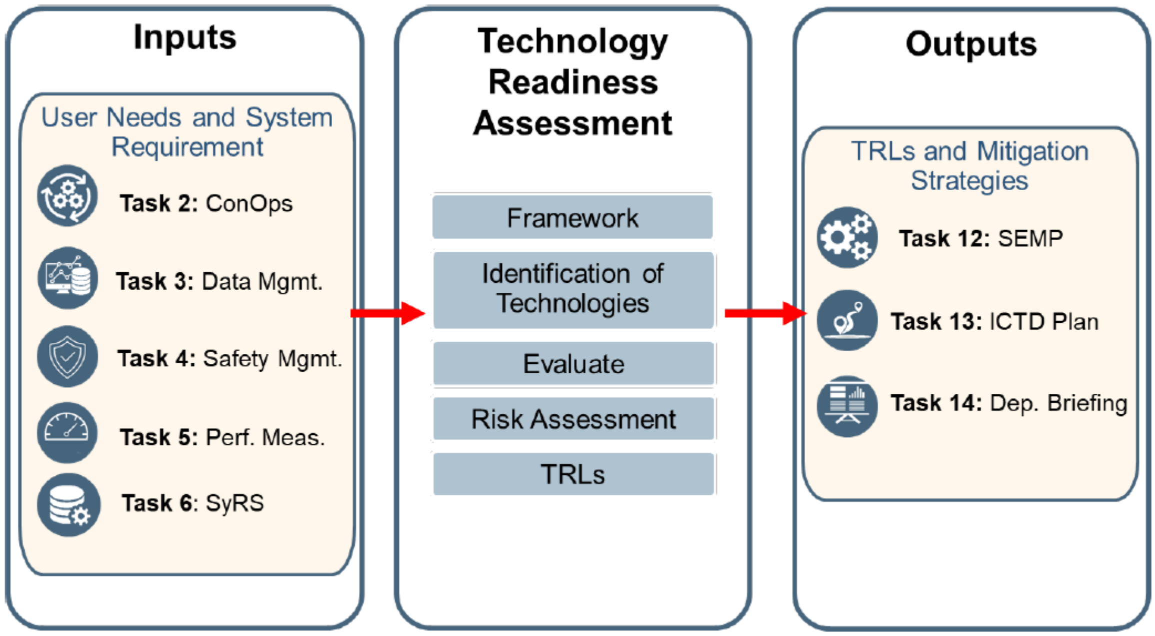

Figure 1. Inputs and outputs of the Enabling Technology Readiness Assessment.
Source: FHWA

1.4 Project Overview

The Greater Buffalo-Niagara Regional Transportation Council (GBNRTC) stablished its vision of the region for 2050 in its "Moving Forward 2050 – A Regional Transportation Plan for Buffalo Niagara" (GBNRTC; University at Buffalo Regional Institute, The SUNY at Buffalo School of Architecture and Planning; Cambridge Systematics; TyLin International, 2018). The plan seeks to guide transportation investments to:

1. *Raise the region's standard of living*
2. Support efficient freight movement
3. Maximize infrastructure resiliency
4. *Support focused growth in communities (urban, suburban, and rural)*
5. *Ensure access to opportunities and services*
6. *Support healthy and safe communities through targeted transportation investment*
7. Strengthen the fiscal health of local governments
8. Preserve and protect a healthy environment and accessible open spaces and waterways
9. *Create a fully integrated and seamless transportation environment*

The Buffalo ITS4US project goals directly align with GBNRTC's goals 1, 4, 5, 6, and 9 (italicized above) by providing innovative tools and services to better enable travelers to make complete trips in and around the BNMC. Furthermore, the proposed system focuses on providing transit access to healthcare and jobs to underserved citizens and allow them to share in the economic development in downtown Buffalo.

To achieve these goals, the proposed system of interest is made of four major subsystems and a variety of data interfaces between them. The four major subsystems include:

- **Complete Trips Platform** – The complete trip platform is the integrated trip planning function for travelers. It includes various modules that allow users to personalize their trip planning, execution, and navigation experience. Specific modules in this subsystem include:

User Profiles	Real-time situation monitoring
Trip Booking	Performance metrics
Trip Planning	Trip history/ledger
Trip Monitoring and Notifications	User Interface (UI): Mobile application
Geolocation and Mapping	UI: Web and Interactive voice response
Navigation	

- **Community Shuttle Subsystem** – The Community Shuttle subsystem provides demand-responsive transit services within a specified zone of operations, using a mix of vehicles, including both human-driven and self-driving shuttles (SDS). The SDS will operate on a predefined route(s), consisting of a set of streets within the zone and pick-up and drop-off locations, but will be responsive to travelers' demand (e.g., it can skip certain pick-up/drop-off locations if there is no demand). The human-driven vehicles will provide door-to-door on demand service within the zone of operation. Modules within this subsystem include both types of vehicles, as well as a Shuttle Operations Center (SOC).
- **Smart Infrastructure Subsystem** – The smart infrastructure subsystem includes wayfinding and orientation for indoor and outdoor, provision of navigation and destination finding through information kiosks (Transportation Information Hub, TIH), augmented communications technologies (Smart Signs), and intersection treatment for hands-free, pedestrian signal requests.
- **Performance Dashboard Subsystem** – This subsystem measures and presents the performance of the system to the agency operating the system.

Figure 2 provides the context diagram for the system. The interfaces are numbered and described later in the document. The following subsections provide more detail on each component's functions and capabilities.

The reader is referred to the Phase 1 Concept of Operations (FHWA-JPO-21-860) for more details on the system's components and functions.

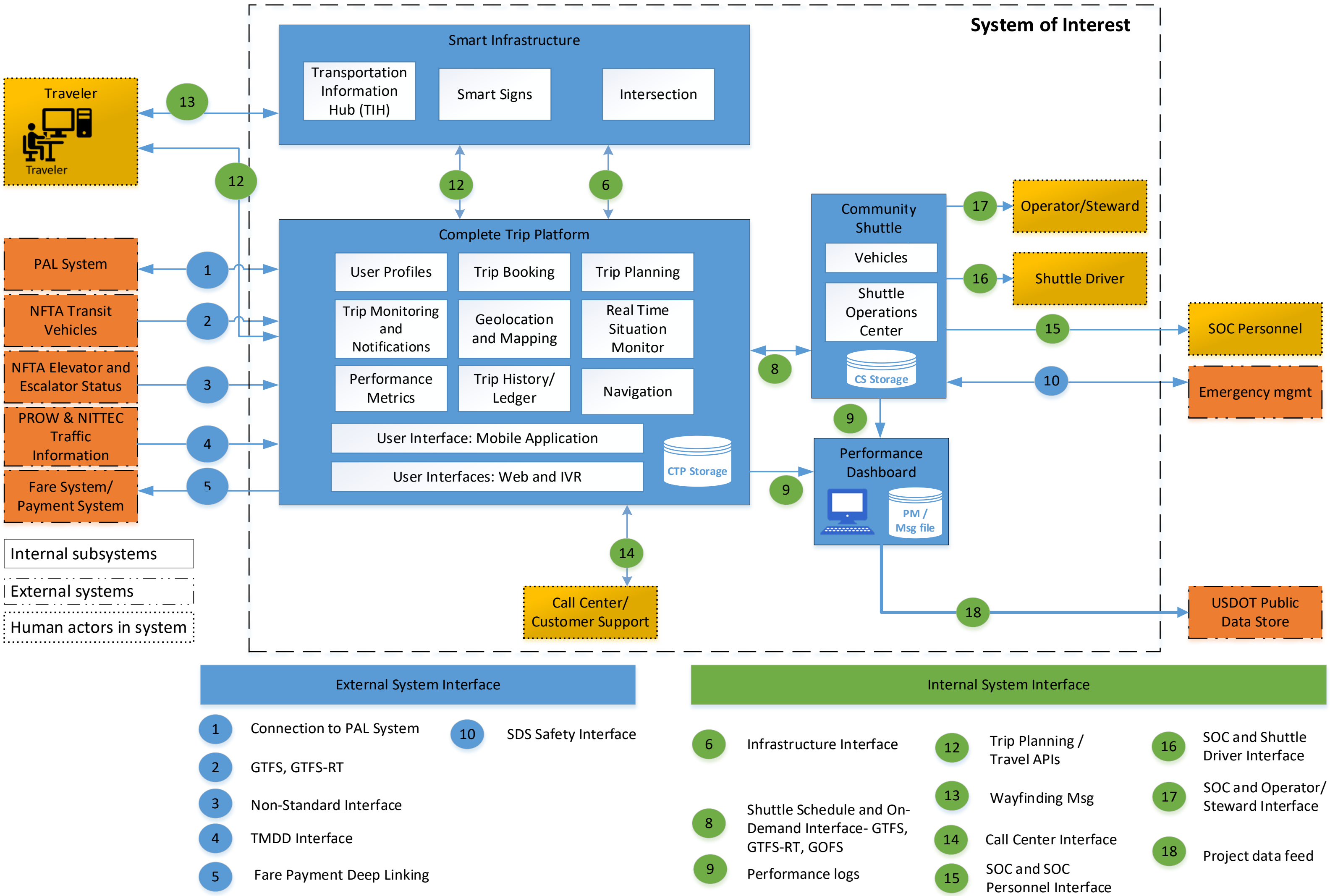

Figure 2. Buffalo, NY ITS4US Full System Deployment Context Diagram with Interfaces and Data Stores.
Source: Buffalo, NY ITS4US

1.4.1 Complete Trip Platform

The Complete Trip Platform (CTP) provides trip planning and travel functions for travelers. The tool is available for registered and non-registered account users. Account holders will be able to interact with other mobility partners for which they have accounts (e.g., NFTA paratransit and community shuttle services), personalize their trip preferences and customize hands-free turn-by-turn notifications, and access to wayfinding assets using components specified in the smart infrastructure subsystem. Non-registered travelers will be able to use the trip plan and travel tools to view accessible paths, transit services and alerts about asset status (e.g., elevator / escalator operations). The functions are described in the following sections.

1.4.2 Community Shuttle Subsystem

The Community Shuttle (CS) subsystem will provide demand-responsive transit services within the Fruit Belt neighborhood. The CS consists of the following three components:

1. The SDS component, which will be a demand-responsive shuttle constrained to operate over a pre-defined route (i.e., a set of streets that satisfy the SDS Operations Design Domain, ODD) and pre-designated pick-up/drop-off locations.

2. The human-driven shuttle (HDS), which will provide door-to-door on-demand service.

3. The Shuttle Operations Center (SOC), which will receive all calls for services and will track the status of each vehicle in the CS fleet.

The envisioned service area for the proposed community shuttle fleet is shown in Figure 3.

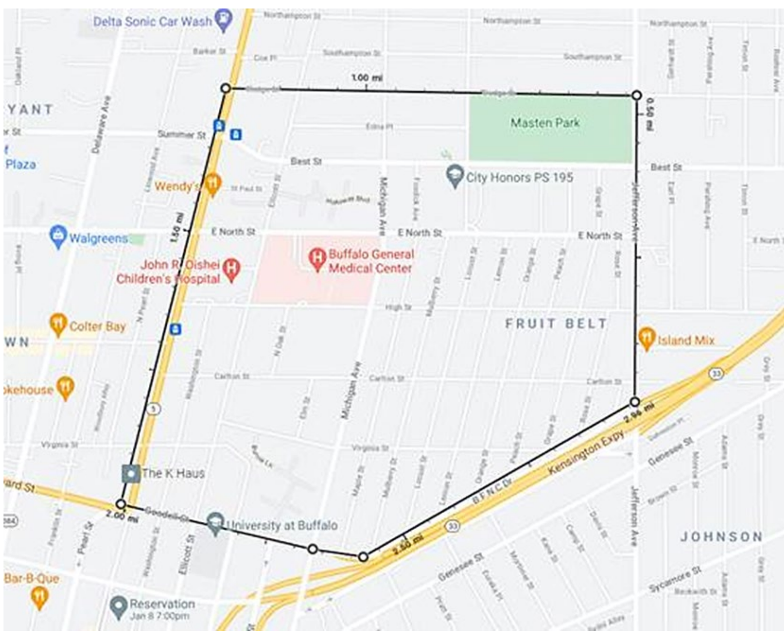

Figure 3. Proposed Service Area for the Community Shuttle.
Source: Buffalo, NY ITS4US & Google Maps.

1.4.3 Smart Infrastructure Subsystem

This subsystem includes “smart” wayfinding components used for indoor and outdoor navigation at public right of ways, parking lots, building/facilities, bus shelters and stations, as well as requests for pedestrian crossing at selected signalized intersections—Main St. & Best St. and Ellicott St. & High St. Additionally, transitioning between indoor and outdoor environments will be seamless. Trip planning and navigation functions will be provisioned through the CTP, with the smart infrastructure assets and communications technologies offering travelers with similar turn-by-turn and hands-free functions. The CTP will also drive the interaction between the travelers’ mobile app and the pedestrian signal request.

Many of these smart components and traveler information products (e.g., trip plans, notifications) are supported by planned physical infrastructure improvements and accessible physical features, to be implemented during the next few years to complement or support the proposed system. These improvements will be combined with the digital components to create a “Smart Infrastructure” subsystem.

1.4.4 Performance Measure Dashboard Subsystem

The Performance Measure Dashboard subsystem monitors, integrates, analyzes, and displays performance measures from other subsystems and external sources. The details of the performance measures will be described in the Performance Measurement and Evaluation Support Plan (PMESP). The subsystem will include functions to ingest log files from the subsystems and external data sources, storage, analytic and visualization tools to display and access current and historic data sets produced from the integrated system.

1.5 References and Applicable Documents

This document utilizes information and processes defined in the following documents:

- Phase 1 Project Management Plan – Buffalo NY ITS4US Deployment Project, specifically the Risk Register.
- Phase 1 Concept of Operations (ConOps) – Buffalo NY ITS4US Deployment Project (FHWA-JPO-21-860).
- Phase 1 Performance Measurement and Evaluation Support Plan (PMESP) – Buffalo NY ITS4US Deployment Project (FHWA-JPO-21-878, dated Oct 25, 2021).
- Phase 1 System Requirements (SyRS) – Buffalo NY ITS4US Deployment Project (FHWA-JPO-21-883, dated Oct 25).
- FHWA Technology Readiness Level Guidebook (FHWA Guidebook) (https://www.fhwa.dot.gov/publications/research/ear/17047/17047.pdf).
- International Organization for Standardization (ISO) Standard 16290 Space systems — Definition of the Technology Readiness Levels (TRLs).

2 Identify Enabling Technologies

2.1 Technology Readiness Framework

The Technology Readiness Framework consists of understanding the technology maturity that will potentially impact deployment of the system concept described in the ConOps. The framework and assessment process follows the *FHWA Technology Readiness Level Guidebook* (FHWA Guidebook) which interprets the TRLs described in the *ISO Standard 16290 Space systems — Definition of the Technology Readiness Levels (TRLs)*. The framework involves describing the technologies needed to deploy the system, assigning a TRL level based on understanding the gaps and maturity level of existing or similar studies, demonstrations, pilots and implementations, and describing the risks to the project in using the technology. Not all the impacts and solutions are known during the concept phase (Phase 1), so alternative studies may be needed during Phase 2 when more details are known about the system solutions.

Each technology contributing to the most promising solution was reviewed by a panel of operators and partner stakeholders who plan, design, develop, operate, and maintain the technologies, as well as technology experts. The enabling technology (ET) list includes hardware, software and interface (services), and their interactions required to implement the concept. The list was derived from technologies described in the subsystems, components, operational environment, constraints, and support environment described in the ConOps (Chapter 5). Several of the ET items using existing technologies which are enhanced to support end-user and operational needs.

It is important to note that mature technologies are not included in the analysis—for instance, the transit onboard systems such as automated vehicle location, mobile data terminals, and communications are not included in this analysis. However, new features or augmented functions are included in the analysis, such as the use of smart signs as an aiding sensor for indoor navigation and the use of the TIH when integrated with the CTP.

Following identification of the technologies, the Buffalo project team ranked the TRL level of the technology based on the criteria set by the FHWA Guidebook (see Table 1). Finally, technology risk is assessed and mitigation plans discussed for those with a high risk impact. The technology readiness TRL assessment process is described in Section 3.1 and the risk identification and mitigation plans are described in Section 4. The mitigation plans may identify alternative solutions or further research and piloting of the selected technologies.

2.2 Enabling Technologies Inventory

The ET inventory was derived from each system subsystem and subsequent component, operational environment, constraints, and support environment. As mentioned above, only technologies that are not considered mature by the industry (i.e., that have not been commercially replicated) are included in this list. Each inventory item includes the following fields:

- **Subsystem(s):** One or two subsystems that use the technology. If the technology is used through the system, the field will display “system”.
- **Description:** a detailed description of the technology and how it is used by the system, subsystem or component.
- **Integration:** description of how the technology is integrated into the system concept and with legacy or existing systems.
- **Procurement:** description of how the technology will be procured, developed or acquired.
- **Traceability**: a mapping of the technology to the (a) system needs as described in the ConOps and (b) the requirements as enumerated in the SySR (forthcoming).

2.2.1 ET-1 Technologies for Integration of Public Right of Way (PROW) Features

Subsystem: CTP

Description: The current system pulls the Open Street Map (OSM) network and features from the open-source data and General Transit Feed Specification (GTFS)/GTFS Realtime and GTFS Flex. Additional accessibility data collected from third parties, both from static and real time sources will be integrated with the existing data and used to generate network link impedances used for optimizing, add attributes and time based events to provide navigation directions and provision notifications and detours to the traveler. The expected datasets include elevator / escalator status, obstacles to walk, temporary closures (e.g., entrances), parking lot pathways, sidewalk elevation, ramps, location of signalized intersections, sidewalk widths and other characteristics. These functions will impact the following CTP components: Geolocation and Mapping; Trip Monitoring and Notifications, and Navigation.

Integration: Additional public right of way (PROW) accessibility information can be integrated as a feature or attribute of the OSM model as currently performed. In addition, a framework for assigning impedances to travel (by edge and node) will need to be developed to optimize travel based on traveler’s preferences and abilities.

Procurement: Modification to the existing software will be conducted to collect, transform, and augment user preferences.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-7. Integrated Data Provision
  - Req-CTP-021 Trip Planning Data validation and processing
  - Req-CTP-022 Reference transportation network
- UN-E-TE-1. Real-time Information
  - Req-CTP-045 Transit and mobility service status information
- UN-E-TE-6. Traveler Guidance

- Req-CTP-048 Sidewalk Data features
- UN-E-TE-7. Indoor Navigation
  - Req-CTP-049 Indoor Pathway features
- UN-E-TE-9. Trip Notifications
  - Req-CS-056 Update CTP on Trip Management
  - Req-CS-056.1 SDS Update CTP on Trip Management
  - Req-CS-056.2 HDS Update CTP on Trip Management
  - Req-CS-056.3 PAL DIRECT Update CTP on Trip Management
  - Req-CTP-060 Trip Notification Triggers
- UN-S-SO-1. Travel Impact Info Integration
  - Req-CTP-084 CTP ingestion of event datasets
- UN-S-SO-3. Wayfinding Infrastructure Integration
  - Req-CTP-110 Transmit to Traveler Time to Cross (Don't Walk)
  - Req-CTP-110.1 Transmit to Traveler Time to Cross (Don't Walk) -- Clock Time Synchronization
  - Req-CTP-110.2 Transmit to Traveler Time to Cross (Don't Walk) -- Countdown
  - Req-CTP-113 PED-X anomalies
- UN-S-SO-4. Indoor Navigation Integration
  - Req-Sy-004 Smart Sign Inventory Access
  - Req-Sy-003 Components Inventory
- UN-S-BO-11. Construction Coordination
  - Req-CTP-108 Ingest Work Zone Event data

2.2.2 ET-2 PAL and HDS Trip Booking Transaction Technology Interface

Subsystems: CTP and NFTA Paratransit Access Line (PAL) software

Description: The PAL Booking application programming interface (API) is a proprietary interface that will enable the CTP to book an on-demand trip using the PAL services for eligible travelers. The same APIs will be used to hail a HDS service. Both services will be deployed using a pilot implementation that meets the needs of the Buffalo ITS4US project. For the ITS4US pilot, the CTP will use the full PAL API services for PAL trips, and the same set of APIs, except the eligibility checking, for the HDS service. The dispatch and operator provisioning will operate without change. The API will ensure a secure transaction initiated by a traveler using the CTP. The transaction, at a minimum, includes registration and linking account (and eligibility from the CTP to PAL), trip availability, trip reservations (and cancellations), trip confirmations, real time estimated arrival times, and reporting information. The PAL software includes these APIs, but they have not yet been integrated with the CTP software. The source code (Open Trip Planner, OTP) used for the CTP has been deployed with reservation service functionality, but not using the NFTA PAL interfaces.

Integration: The integration requires two major efforts:

- Message orchestration and processing of the PAL software APIs by CTP.
- Security and privacy provisions to ensure that the data complies with security policies. For example, the data exchange should not include any medial or personal information and may use only a token to link account information.

Procurement: Modification to existing software for both the PAL and CTP will be applied during Phase 2 to accomplish this task. Because the PAL software is proprietary, it is assumed that a non-disclosure and licensing agreement will need to be generated prior to development.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-1. Spontaneous Trip
  - Req-CS-036 On-Demand Routing and Dispatch
  - Req-CS-036.2 HDS on-demand routing and Dispatch
  - Req-CS-036.3 PAL spontaneous routing and Dispatch
  - Req-CS-93 CS Estimated Time of Arrival Service Level
  - Req-CTP-001 Reservation Planning Services
  - Req-CTP-001.1 Reservations -- check service
  - Req-CTP-001.2 Reservations -- booking service
  - Req-CTP-001.3 Reservations -- confirm service
  - Req-CTP-001.4 Reservations -- change service
  - Req-CTP-001.5 Reservations -- cancel service
  - Req-CTP-001.6 Reservations -- view service
  - Req-CTP-008 Mobility Provider Reservations APIs used by CTP
  - Req-Sy-009 Access to Spontaneous Mobility Services via CTP
  - Req-Sy-009.2 Access to HDS Mobility Services via CTP
  - Req-Sy-009.3 Access to PAL Spontaneous Services via CTP
  - Req-Sy-009.4 Access to PAL Direct services via CTP
  - Req-Sy-012 Trip Planning and Booking Service Level Agreements
- UN-E-TP-2. Coverage
  - Req-CTP-011 Buffalo and NFTA Service Coverage
  - Req-CTP-012 Data of Mobility Services in Project Region
- UN-E-TP-6. Integrated Multimodal Service
  - Req-CTP-019 Integrated Trip Planning services
  - Req-CTP-019.2 Integrated Trip Planning -- NFTA PAL options
  - Req-CTP-019.4 Integrated Trip Planning -- CS HDS
- UN-E-TP-11. PAL Profile Integration

  - Req-CTP-042 CTP Travel Account Link with PAL Direct
- UN-E-TP-12. Shuttle Trip Booking and Reservation
  - Req-CS-040 Validate Reservation
  - Req-CS-040.2 Validate HDS Reservation
  - Req-CS-040.3 Validate PAL Spontaneous Reservation
- UN-E-TP-13. PAL Trip Booking
  - Req-CS-040 Validate Reservation
  - Req-CS-040.3 Validate PAL Spontaneous Reservation
  - Req-CS-045 Mobility Provider Booking API Specifications
  - Req-CS-045.3 PAL Booking API Specification
  - Req-CS-046 Booking Status API
  - Req-CS-046.3 PAL Booking Status API
- UN-E-TE-1. Real-time Information
  - Req-CS-043 Tracking CS vehicle operations
  - Req-CS-043.2 Track HDS Performance
  - Req-CS-049 Mobility Provider Routing Management
  - Req-CS-049.2 HDS Scheduling and Routing
  - Req-CS-049.3 PAL DIRECT Scheduling and Routing
  - Req-CS-055 CS Trip Monitor Management
  - Req-CS-055.2 HDS Trip Monitor Management
  - Req-CTP-045 Transit and mobility service status information
  - Req-CTP-047 Rerouting trip plan
- UN-E-TE-14. Nighttime Travel
  - Req-CS-077 CS Hours of Operations
  - Req-CS-077.2 HDS Hours of Operations
  - Req-CS-077.3 PAL Spontaneous Hours of Operations
- UN-S-SO-5. Reporting Issues
  - Req-CS-88 Report health status to CTP
  - Req-CS-88.2 Report HDS Operating Status to CTP
  - Req-CS-88.3 Report PAL Operating Status to CTP
- UN-S-SO-13. Open Architecture and Interoperability
  - Req-CS-045 Mobility Provider Booking API Specifications
  - Req-CS-045.2 HDS Booking API Specification
  - Req-CS-045.3 PAL Booking API Specification
  - Req-CS-046 Booking Status API
  - Req-CS-046.2 HDS Booking Status API

- Req-CS-046.3 PAL Booking Status API
- Req-INT-011 Reservation API Specifications
- Req-INT-011.2 HDS Reservation API Specification
- Req-INT-011.3 PAL DIRECT Reservation API Specification

- UN-S-BO-6. Operations Reports
  - Req-CS-080 Monitor CS travel anomalies
  - Req-CS-080.2 Monitor HDS travel anomalies

2.2.3 ET-3 Community Shuttle Trip Booking Transaction Technology Interfaces

Subsystems: CTP and SOC for the SDS.

Description: The CTP will engage the SDS SOC in a request for availability, reservations (cancelation), confirmation, and provision of information on real time pick up/drop off times/locations. The SDS will operate on a fixed set of roads, and the shuttle will pick up and drop off travelers at fixed stops. Although the specific reservations services and real time status information have not yet been acquired, the interface technology – message formats, orchestration, and internal processing is well established and supported by several existing and emerging tools and standards.

Integration: The integration requires two major efforts:

- Message orchestration and processing of the new booking messages by CTP.
- Security and privacy provisions to ensure that the data complies with security policies.

Procurement: Modification to existing CTP software will be conducted to incorporate the web-based APIs provisioned by a CS booking system. The modifications have been made by the CTP core software in other implementations. The SOC procurement will include booking, scheduling, and routing tools along with vehicle tracking and monitoring software.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-1. Spontaneous Trip
  - Req-CS-036 On-Demand Routing and Dispatch
  - Req-CS-036.1 SDS on-demand routing and Dispatch
  - Req-CS-93 CS Estimated Time of Arrival Service Level
  - Req-CTP-001 Reservation Planning Services
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  - Req-CTP-001.3 Reservations -- confirm service
  - Req-CTP-001.4 Reservations -- change service
  - Req-CTP-001.5 Reservations -- cancel service

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- Req-CTP-008 Mobility Provider Reservations APIs used by CTP
- Req-Sy-009 Access to Spontaneous Mobility Services via CTP
- Req-Sy-009.1 Access to SDS Mobility Services via CTP

- UN-E-TP-2. Coverage
  - Req-CTP-011 Buffalo and NFTA Service Coverage
  - Req-CTP-012 Data of Mobility Services in Project Region
  - Req-Sy-012.1 CS Response Time
- UN-E-TP-6. Integrated Multimodal Service
  - Req-CTP-019 Integrated Trip Planning services
  - Req-CTP-019.3 Integrated Trip Planning -- CS SDS
- UN-E-TP-12. Shuttle Trip Booking and Reservation
  - Req-CS-040 Validate Reservation
  - Req-CS-040.1 Validate SDS Reservation
- UN-E-TE-1. Real-time Information
  - Req-CS-043 Tracking CS vehicle operations
  - Req-CS-043.1 Track SDS Performance
  - Req-CS-049 Mobility Provider Routing Management
  - Req-CS-049.1 SDS Scheduling and Routing
  - Req-CS-055 CS Trip Monitor Management
  - Req-CS-055.1 SDS Trip Monitor Management
  - Req-CTP-047 Rerouting trip plan
- UN-E-TE-14. Nighttime Travel
  - Req-CS-077 CS Hours of Operations
  - Req-CS-077.1 SDS Hours of Operations
- UN-S-SO-5. Reporting Issues
  - Req-CS-88 Report health status to CTP
  - Req-CS-88.1 Report SDS Operating Status to CTP
- UN-S-SO-13. Open Architecture and Interoperability
  - Req-CS-045 Mobility Provider Booking API Specifications
  - Req-CS-045.1 SDS Booking API Specification
  - Req-CS-046 Booking Status API
  - Req-CS-046.1 SDS Booking Status API
  - Req-CS-92 Open Architecture SDS System
  - Req-INT-011 Reservation API Specifications
  - Req-INT-011.1 SDS Reservation API Specification

- UN-S-BO-6. Operations Reports
  - Req-CS-080 Monitor CS travel anomalies
  - Req-CS-080.1 Monitor SDS travel anomalies

2.2.4 ET-4 Navigation Technology Integration with Smart Signs

Subsystems: CTP and Smart Infrastructure (Signs)

Description: The CTP will use smart signs located at strategic facility corridors, junctions, and vertical conveyance, as well as transit shelters and stations to correct wayfinding and routing algorithms using known, precise locations. The CTP will connect, access identifiers, and match the smart sign signals to known locations to support travelers with more accurate information. These smart signs will be used to replace Global Positioning System (GPS) when it cannot be accessed (e.g., indoors and underground), and use inertial sensors (accelerometers, gyroscopes) to count steps to next known sensor locations. There are several technologies that support these use cases. Two technologies are under consideration: Near Field Communication (NFC) tags and Bluetooth Low Energy (BLE) beacons. The NFC tags support destination confirmation while the BLE beacons support navigation and wayfinding.

- **NFC technology:** Use of the NFC tags are based on an existing pilot underway at a partner facility. The tag is assigned a unique identifier that is read by any NFC enabled smart phone and links the user to a central database with information provided by the destination (e.g., destination, hours of operation). If associated with an elevator bank, the identifier can trigger the app to provide elevator status, or at a bus shelter, it can trigger a notification about the next bus arrival time. The distance to activate the tag is about 4 centimeters which requires the user be close to the tag. To that end, the tags will be positioned to comply with American Disabilities Act (ADA) provisions to be accessible for people with mobility disabilities. This technology has been piloted and that pilot deployment is now complete. Deployment at VIA is planned for early 2022 (see Appendix B. Technical References, TR-3 Subryan). The CTP will utilize the code base to embed the functionality into the mobile app.

- **BLE technology:** Bluetooth Low Energy is an effective wireless standard for indoor location because of its physical range and wide support in smartphone devices. Users often have Bluetooth enabled on their phones, due to the variety of emerging peripherals like smart watches, headsets, earbuds, AirTags, speakers, car door locks, smart home locks, and so forth. The BLE beacons are meant for devices that are powered by coin batteries, BLE was released as a subset of Bluetooth 4.0 in 2011. This made a new category of beacon devices possible, that run for years on a battery while regularly transmitting small presence advertisements. When a smartphone receives these presence messages, it can approximate the user distance to the beacon device using the Received Signal Strength Indicator (RSSI). An app can locate the user relative to fixed beacon positions without the need for reliable GPS satellite signals indoors, and also monitor the distance changes over time to better detect the user's direction of movement. In 2016 with the release of Bluetooth 5, compliant beacons located in indoor environments provide four times the range of prior-generation devices. In 2019, Bluetooth 5.1 standard added Angle of Arrival and Angle of Departure for location tracking use cases. Use of the BLE beacons are commercially available to support wayfinding deployments (See Appendix B, TR-3 publications). The beacon provides location information while installed at a fixed location like a facility entrance, elevator bank, and bus shelter. The CTP can used to aid mobile app navigation and monitoring functions (both on-line and off-line modes). Technology deployments use “aiding” sensors at fixed points to correct inertial sensor (e.g., accelerometers, gyroscopes). Typical algorithms that would use these data include map matching or Kalman filters. The BLE beacons can be tuned to provide accuracy at different proximity resolutions. There have many pilots and operational environments that BLE has been implemented for wayfinding and navigation. These include the following:

- The Metropolitan Area of Porto conducted a pilot study using BLE, mounting devices on buses and stations so that a ticketing smartphone app could automatically detect the vehicles and transit locations. A passenger can step onto a bus and the app would be able to automatically detect the route based on the device's advertisement, and know where the passenger steps off. This provided end-to-end tracking of users' trips and was put into production in 2018. A passive wireless Be-In/Be-Out (BIBO) system shows that Bluetooth can serve as a very local presence sensor without the need for users to directly interact with physical infrastructure. (Appendix TR-3, Porto).

- Going beyond presence detection, the University of California Santa Cruz in 2021 was able to use BLE with the RSSI measurements to detect the user's location within the vehicle, with less than one meter of accuracy. They placed four Kontakt Tough TB15-1 BLE devices on a vehicle, transmitting three times per second, with an anticipated battery life of up to 6.5 years. This greatly exceeds the ambitions of this project for helping to guide users within buildings, where the signals can be transmitted much less often (saving battery life) and require on the order of one tenth the distance accuracy. (Appendix B TR-3, Santa Cruz).

- The most modern indoor navigation approach is using machine learning in conjunction with BLE devices, to learn the patterns of RSSI measurements in a building and avoid the need to do building-specific calibrations. (Appendix B TR-3 Sun Wei).

Integration: The CTP will need to connect to the sensor using specialized code, store a database with locations, names and other pertinent information (as needed by the various use cases), implement algorithms to improve traveler orientation, navigation and destination confirmation. Appropriate material will be added to the training curriculum to educate and train users on how to pair their phones with the Bluetooth beacons. This functionality will supplement mobile handset positional and orientation accuracy.

Procurement: The acquisition of either or both BLE beacons and NFC tags will be gained through procurement. Vendor tools (for example, a software development kit) will be used to help develop software that is integrated with CTP.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-10. Assistive Technology Compatibility
    - Req-CTP-041 Assistive Technology Compatibility

- UN-E-TE-5. Pick-up and Drop-off Zones
  - Req-SI-028 Public kiosks
- UN-E-TE-6. Traveler Guidance
  - Req-SI-027 Transmit Time to Cross (Don't Walk)
  - Req-SI-032 Smart Sign Data Sharing
- UN-E-TE-7. Indoor Navigation
  - Req-CTP-049 Indoor Pathway features
  - Req-SI-031 Smart Sign Data Storing
  - Req-SI-032 Smart Sign Data Sharing
- UN-S-SO-4. Indoor Navigation Integration
  - Req-Sy-004 Smart Sign Inventory Access
  - Req-CTP-117 Smart Signs using Common communications protocols
  - Req-Sy-003 Components Inventory
- UN-S-SO-15. Location Accuracy
  - Req-CTP-101 Tune location settings

2.2.5 ET-5 Mobile Pedestrian Crossing Technology Interface

Subsystems: CTP and Smart Infrastructure (Signal systems and pedestrian crossing signal request)

Description: As described in the ConOps Section 6.4.1, Use Case 10 Pedestrian Signal Crossing, a traveler using a smart phone will be able to automatically request actuation of the pedestrian Walk signal for a pre-determined cross walk. The request will be made using National Transportation Communications for ITS Protocols (NTCIP) 1211 Signal Control and Prioritization message set from their smart phone. The message will be triggered from their phone based on their proximity from the intersection is coordination with their trip plan. The request message will identify the signal phase (and crosswalk) desired. In turn the signal controller will respond with the periodic status messages, confirming receipt of request, providing information on desired time until walk signal is active, and time when walk signal is deactivated. During the exchange, the CTP will provide countdown information to the traveler (upon their request).

Integration: The implementation requires a modification to the mobile app code. The mobile app already supports the functions needed to implement the use case – interfacing with a third party via Bluetooth, WiFi or cellular, triggering message exchanges based on traveler proximity, and generating messages based on existing standards. The signal system supports NTCIP protocols, and the pedestrian signal request message leverages transit signal priority message exchanges which signal control vendors have implemented in the past. The gateway that receives and transmits the message (and serves as the signal request generator) is described in ET-15 (see Section 2.2.15).

Procurement: The implementation requires a modification to the mobile app code and traffic signal controller code to implement the logic.

Traceability of User Need(s) and System Requirements:

- UN-S-SO-2. Intersection Movement
  - Req-CTP-057 PED-X Request Message
  - Req-CTP-058 PED-X Request Cancel Message
  - Req-CTP-059 PED-X Request Clear Message
  - Req-CTP-085 CTP ingestion of traffic signal control operation data
  - Req-SI-027 Transmit Time to Cross (Don't Walk)

2.2.6 ET-6 Mobile App Positioning and Orientation Technology

Subsystem: CTP Mobile App

Description: Mobile app handsets do not provide different levels of positional and orientation accuracy. Furthermore, detection of a person traveling or oriented in the wrong direction is typically delayed until a person has traveled at least "30 feet". The mobile app if dependent on the native software development library (SDK) and the handset's capabilities. The positional and orientation error budgets are not consistent across handsets, operating systems and are further exacerbated by the user's configuration settings. Better knowledge of the error budgets and optimizing geolocational settings will enhance the systems accuracy and improve its power consumption. Instructing the user to optimize their settings will improve and normalize accuracy across handsets. In addition, the NY City (NYC) Connected Vehicle (CV) Pilot[1] recommended positioning a traveler's mobile app in a stationary, central spot (for example, in a phone mount or harness) during operations which improved orientation and positional accuracy. Both the configuration settings and stable phone placement stem from user training, rather than technology improvements.

Integration: Many of these features are already integrated into current trip planning mobile app settings, however, a combination of design improvements, user instructions for updating settings and tailoring algorithms to deal with system error budgets will improve accuracy and direction detection. These are planned for applying to specific use cases including indoor navigation, intersection crossing, destination confirmation (e.g., pickup locations), among others.

Procurement: These functions will be implemented through modification of the existing code base. The improvements can also be achieved through user training for configuration mobile phone settings and placing the handset in a stable location.

Traceability of User Need(s) and System Requirements:

- UN-E-TE-5. Pick-up and Drop-off Zones
  - Req-CS-029 Designated Pickup/Drop off Stops

[1] Interview with Robert Rausch on NYC CV Pilot Pedestrian Signal application (2021-07-29)

- UN-E-TE-6. Traveler Guidance
  - Req-SI-032 Smart Sign Data Sharing
- UN-E-TE-7. Indoor Navigation
  - Req-CTP-049 Indoor Pathway features
  - Req-SI-031 Smart Sign Data Storing
  - Req-SI-032 Smart Sign Data Sharing
- UN-S-SO-4. Indoor Navigation Integration
  - Req-Sy-004 Smart Sign Inventory Access
  - Req-CTP-117 Smart Signs using Common communications protocols
  - Req-Sy-003 Components Inventory
- UN-S-SO-15. Location Accuracy
  - Req-CTP-101 Tune location settings

2.2.7 ET-7 Mobile Accessibility Technology

Subsystem: CTP Mobile App

Description: User needs described in the ConOps identified several features to improve user interface accessibility. Among the accessibility features that were identified include:

- For people with cognitive disability or limited English proficiency: Clear, simple instructions, or presentation of icons and symbols, easy to manipulate, use of zoom to focus important text, rely on consistent navigation and logical content layout, and simple error messages.

- For people with hearing loss or who are deaf: Rely on text, using vibration setting to alert to notification or alert, present notification with person signing.

- For people with visual loss or who are blind: using a screen reader to assist with text and forms, using a keyboard or consistent navigation and logical content layout for transitioning methods to navigate and interact with online content (rather than a mouse or finger), relying on audio descriptions to understand key visual elements. Other features: use mobile phone controls, screen to zoom and magnify content and rely on color contrast.

- For people with low dexterity user disabilities: rely on consistent navigation and logical content layout, and simple error messages, voice activated mobile phone controls

To achieve “one Complete Trip mobile app” to address all accessibility features will require that the app make use of best practices for baking in accessibility. Best practices in the industry direct developers to use mobile native controls and SDK because they typically have accessibility built in. Both Apple and Google provide accessibility guidelines for developers. Adopting these guidelines increase the availability of the app features and functions. These will be of specific importance in hands-free use.

Integration: Development of accessibility features applied during the Agile development process to both retrofit existing functions and services on the Android and Apple iOS based phones, and to add new features. Stakeholders from multiple underserved communities will help drive the priority accessibility methods. In addition, the Web Content Accessibility Guidelines 2.1 will be applied, and robust testing based on user persona will be conducted to test the guidelines and usability.

Procurement: Modification to the existing code and use of native operating software tools will be applied to apply the technology.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-8. Easy to Use and Flexible App
  - Req-CTP-024 Accessibility Feature Compliance
  - Req-CTP-025 End-User Driven User Experience
  - Req-CTP-026 Communications Channels
  - Req-CTP-027 On-line / off-line data usage and tracking
- UN-E-TE-9. Trip Notifications
  - Req-CTP-060 Trip Notification Triggers
  - Req-CTP-062 Trip notification to preferred user interface
- UN-E-TE-10. Notification Preferences
  - Req-CTP-063 Trip notification preferences

2.2.8 ET-8 Wearables and Interfaces Technology

Subsystem: CTP Mobile app (and wearables such as smart watch).

Description: Wearables are potential supplementary tools to support hands-free wayfinding and navigation for underserved populations. A wearable may alert a traveler through a vibration that a notification was received, a community shuttle is approaching, a direction to turn or cross an intersection is within a specified distance, or the pedestrian signal request was received. For a person with low vision, a message voice over may be annunciated, for a person with hearing loss, the text message may be scrolled. The equipment is easier to position on a person and provides on-person notification and navigation alerts rather than on a smart phone that may be tucked into backpack or handbag. The form factor differs from the mobile app so the types of information provided to the traveler will differ from the mobile app.

Integration: Wearables may be driven by the host service (e.g., mobile app) or be a native app downloaded to the device. Some of the wearable's tools are compatible with the native mobile app SDK, others require native programming.

Procurement: Development of software is needed to add wearable functions to the CTP.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-8. Easy to Use and Flexible App

  - Req-CTP-024 Accessibility Feature Compliance
  - Req-CTP-026 Communications Channels
  - Req-CTP-027 On-line / off-line data usage and tracking
- UN-E-TE-9. Trip Notifications
  - Req-CTP-060 Trip Notification Triggers
  - Req-CTP-062 Trip notification to preferred user interface
- UN-E-TE-10. Notification Preferences
  - Req-CTP-063 Trip notification preferences

2.2.9 ET-9 Self-Driving Shuttle (SDS) Automated Driving System Technology

Subsystem: Community Shuttle SDS

Description: SDSs using Automated Driving System (ADS) technology offer great promise for so many segments of society lacking mobility. According to the USDOT NHTSA report (2017), trip-making for the over 25 million Americans with disabilities is a task challenged by several obstacles. These obstacles result in Persons with Disabilities (PWDs) making significantly fewer trips compared to those without disabilities. Moreover, with the elderly population being the fastest growing segment in the US, those with mobility challenges are likely to increase substantially in the coming years. Besides PWDs and the elderly, another group that can benefit from SDS are the economically disadvantaged; for which car ownership may have a prohibitive cost and transit options are lacking. ADS have been developed and extensively tested, and now implemented in several locations across North America and the world. All of these ADS programs are governed by extensive safety protocols, and have demonstrated excellent safety records, as has been publicly reported to various agencies such as the California Department of Transportation.

Major components of ADS include:

1) Hardware**: I**ncludes the sensor set and on-board computers, integrated into the SDS systems.

   a. The sensor set likely consists of Light Detection and Ranging (rotating lasers), cameras, radar, audio, and inertial measurement systems. The resulting sensor data, along with high- definition maps, are integrated to provide a comprehensive and accurate definition of the surrounding driving environment.

   b. On-board computers are an essential component of ADS and are designed for fail-proof operation and safe from cyber-attacks and malicious activity. Robust operation includes redundant systems.

   c. ADS hardware and software communicate with vehicle hardware to provide steering, braking and acceleration commands through drive by wire technology.

2) Software: ADS software has many vital functions including these major elements:

a. Perception: Detects and classifies objects, and measures their motion over time including speed, acceleration, and heading. This is a critical component of safety to assess all elements of the environment including pedestrians and vehicles of all types and ensure there are no unsafe interactions.

b. Prediction: Models trajectories for every object through time and space so that the ADS has a dynamic picture of its environment.

c. Planning: The planning function determines the vehicle trajectory to provide a safe path for the SDS along its route to intermediate destinations.

The promise of SDSs with ADS is that transportation can be provided at reasonable prices with high levels of service. While this project expects that safety stewards will be onboard through testing and implementation, there is a longer-term expectation that SDS in some applications may be able to eventually operate safely and effectively without attendants onboard.

Integration: While the technology for the ADS of the SDS is turnkey, integrated hardware and software with internal controls and monitored by the SOC, the ADS technologies will still need to be integrated with many of the other technologies which will deployed as part of the Buffalo ITS4US project. Specifically, the SDS ADS technology will need to be integrated with the shuttle's: (1) in-vehicle monitoring and communications technologies (ET-10); (2) passenger information system technologies (ET-11); (3) accessibility support technologies (ET-12); (4) operations support technologies (ET-13); and fleet management technologies (ET-14). Integration with in-vehicle monitoring and communications (ET-10) will allow for monitoring the status or "health" of the various sensors of the ADS, and the status of passengers onboard (properly secured, cleared the door, etc.). ADS will only engage once the system confirms that all sensors are working properly, and all passengers are properly secured and seated. Integration with passenger information technologies (ET-11) is needed to enable the notification to passengers regarding trip progress, landmarks passed, detours, and approaching shuttle stops. Integration with accessibility support technologies (ET-12) is required for coordinating the deployment of the shuttle's ramps, door opening and closing. Integration with operations support technologies will help determine whether a given driving environment or condition satisfies the ODD for the SDS, a critical pre-requisite for driving autonomously. Finally, integration with the fleet management technologies is needed for the SDS to receive its assigned route to pick-up or drop-off a passenger.

In addition, the aforementioned integrations with components of the CS subsystem, there is a need to integrate the ADS technologies with the CTP subsystem as well, as explained later in this document.

Procurement: There is a substantial and constantly growing set of companies providing SDS vehicles with advanced and safe ADS technology. The selection of a SDS partner will ultimately be decided with those able to provide proven ADS technology, meeting user needs, in a willing partnership, at an agreed economic structure. While the project team has existing relationships with SDS providers such as Local Motors and its Olli vehicles, there will be engagement with a variety or providers to select the best combination of user needs, safe technology, and economics. In selecting the specific technology providers, the needs of the Buffalo mobility challenged community will be at the forefront of consideration. Vehicle accessibility as detailed in ET-12 will be an important criterion considered in selection of the SDS.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-1. Spontaneous Trip
  - Req-CS-036 On-Demand Routing and Dispatch
  - Req-CS-036.1 SDS on-demand routing and Dispatch
  - Req-Sy-009 Access to Spontaneous Mobility Services via CTP
  - Req-Sy-009.1 Access to SDS Mobility Services via CTP
  - Req-Sy-012 Trip Planning and Booking Service Level Agreements
- UN-E-TP-2. Coverage
  - Req-CTP-012 Data of Mobility Services in Project Region
  - Req-Sy-012.1 CS Response Time
- UN-E-TP-14. Cost to User
  - Non-technical need, no requirement traced to it.
- UN-S-SO-11. System Reliability
  - Req-CS-018 CS Vehicle Health Monitoring
  - Req-CS-018.1 SDS Sensor Health Monitoring
  - Req-CS-018.2 SDS Communication Health Monitoring
  - Req-CS-018.3 SDS Safety Asset Health Monitoring
  - Req-CS-019 Monitor Communications
- UN-S-BO-1. System Operation Costs
  - Non-technical need, no requirement traced to it.
- UN-S-BO-5. Filling Transit Gaps
  - Req-Sy-011 Geographic Coverage

2.2.10 ET-10 SDS In-vehicle Monitoring and Communications Technology

Subsystem: Community Shuttle SDS

Description: The SDS will be equipped with technologies to:

ET-10.1 Boarding/Alighting Monitoring – monitor passengers as they board and alight from the SDS to ensure they have safely boarded or got off the vehicle and are properly secured or seated;

ET-10.2 SDS Cyber/Physical Elements Monitoring – monitor the “health” of the *cyber* and *physical* elements of the SDS and the accessibility support mechanisms; and

ET-10.3 V2X Communications – enable communications between the SDS and SOC to

a) monitor passenger safety in boarding, alighting and in-vehicle behavior;

b) authenticate rider reservations and interface with rider information devices such as hearing aids, smart phones, and smartwatches.

For ET-10.1, monitoring passengers boarding and alighting could be implemented through an adaptation sensor technologies, especially systems that use digital cameras 3-dimensional vision software. The technologies to monitor passenger boarding/alighting may not be integrated in the turnkey SOC/SDS components; rather a third party system may be deployed using separate component and communication channels to provide the information to the SOC.

ET-10.2 SDS cyber/physical elements monitoring technologies that monitor in-vehicle activities are implemented in many transit and ride-hailing vehicles as third party commercial of the shelf (COTS) products. Similar to the vision software described in the ET-10.1, these could be implemented using the same technology.

ET-10.3 V2X Communications is a mature technology to communicate between the SDS and SOC and other in-vehicle communication channels. The implementation is envisioned as a router that may include multiple radio channels (e.g., cellular, WiFi, Bluetooth) to connect to the SOC or rider technologies. The communication channel would work as separate channels from the integrated vendor command and control functions. The services supported by this communications channel would include numerous methods for rider authentication (e.g., rider check-in, see TR-2 AMP). For riders who do not possess a smart phone, for example, travelers who booked reservations via the call center or through a Traveler Information Hub (TIH), other methods such as a QR code printed on paper or electronic identification method may be implemented (and checked by the SDS steward).

Integration: In-vehicle monitoring and communications technologies will need to be deployed in the SDS vehicle. Communications strategies are available as off-the-shelf technologies and use standard protocols and open APIs to process the information. The integration may also involve interfacing with the CTP mobile app which has equivalent functionality (e.g., display Quick Response (QR) code or authenticate through BLE). Third party devices that monitor passengers may need to be deployed along with supplementary communications to exchange information with the SOC. Other information can be stored until off-loaded at the end of the day.

Procurement: Although the SOC/SDS procurement will be a turnkey procurement, separate functionality will support procurement of COTS to monitor passenger safety and interaction with the services if not already integrated into the vendor ADS system.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-8. Easy to Use and Flexible App
    - Req-CTP-026 Communications Channels
- UN-E-TE-3. (OPTIONAL) Seat Availability
    - Req-CS-065 Determine occupancy status of wheelchair securement systems
- UN-E-TE-9. Trip Notifications
    - Req-CS-056 Update CTP on Trip Management
    - Req-CS-056.1 SDS Update CTP on Trip Management

- UN-E-TS-4. Low-Tech/Non-Smartphone Accessibility
  - Req-CTP-073 Trusted third party access
- UN-S-SO-6. Offline Use
  - Req-CTP-088 UI to Call Center
  - Req-SI-028 Public kiosks
  - Req-Sy-008 Call Center
- UN-S-SO-9. Hardware Characteristics
  - Req-CS-91 External/Internal Monitoring
- UN-S-SO-10. Secure Software
  - Req-CS-071 Cybersecurity risk assessment
  - Req-CS-072 Access to SDS onboard computers
  - Req-CS-073 Security Breach Response
  - Req-CS-074 Defense against Spoofing Attacks on sensors
  - Req-CS-075 New Software Releases
  - Req-CS-084 Secure Mobility Provider Trip Reporting
  - Req-CS-084.1 Secure SDS Trip Reporting information
  - Req-Sy-013 Data security
- UN-S-SO-14. Safety of Services
  - Req-CS-007 Automatic Doors
  - Req-CS-007.1 Automatic Doors - Open
  - Req-CS-007.2 Automatic Doors - Close
  - Req-CS-007.3 Automatic Doors - Malfunction

2.2.11 ET-11 SDS Passenger Information System

Subsystem: Community Shuttle SDS

Description: The SDS Passenger Information System will have various components so that passengers with visual, hearing, or limited English language speakers can safely access the SDS to find, board, and travel in the SDS. The passenger information system on the SDS will be an original equipment manufacturer (OEM) or after-market product. The specific features/equipment have some variability depending on the SDS provider, but are likely to include:

- In-vehicle audio that informs passengers as to the status of vehicle operation such as doors closing, departure imminent, destination approaching.

- In-vehicle visual information, ideally through an in-vehicle screen, that shows vehicle status, location, and trip progress.

- In-vehicle visual and audio Information about the environment surrounding the vehicle including: a) location, route, certain landmarks; b) traffic accidents and incidents; and c) deviations from route or why the SDS may be stopping.
- Braille lettering for any in-vehicle functions that require passenger interaction.
- Auditory and haptic notification of estimated time of arrival and when the SDS is near the pickup/drop-off location.
- Universal icons, instructional videos.
- External announcements and visual cues about the vehicle number, destination and persons who reserved the vehicle.
- Communications device for emergency calls to the SOC.

The passenger information system is responsible for communicating to riders information about:

- Travel information including current location, route, destination, next pickup/dropoff point, landmarks.
- Situational awareness about events such as incidents.
- Deviations and delays related to trip.
- Public safety messages including doors open, board now, secure your seat belt, close door, etc.

The Passenger Information System will also provide auditory and visual notifications of estimated time of arrival and when the SDS is near the pickup/dropoff location. Moreover, the SDS will have on-board monitors to display current location on a map display and show status indicators for normal operation.

In addition, the SDS Passenger Information System may include outlets (phone jack) or Bluetooth interfaces that support passenger assistive devices including hearing aids or the CTP mobile app.

Integration: The SDS Passenger Information System will be fully integrated into the SDS vehicle in the turnkey procurement. The SDS information system also will be integrated with the SOC which will monitor the operations of the information provision. The provision of messages displayed or announced over the various media will be coordinated through a passenger information management control system that manages the media channels. In addition, the onboard communication device will allow a passenger to contact the SOC in the case of an emergency.

In addition, the SDS Passenger Information System is expected to be integrated with the CTP mobile app using status data delivered through center-to-center vehicle tracking and status messages. The details will depend on the vehicle features. The CTP will be used for passengers to understand vehicle status and location.

Procurement: The provider of the SDS will also be responsible to supply integrated passenger information components. The project team will work with vendors to test and validate Passenger Information System components. Alternative technologies that are currently implemented in most transit vehicles could be retrofitted to support many of these functions if the desired technologies are not available in a turnkey ADS.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-4. Independence
  - Non-technical need, no requirement traced to this need.
- UN-E-TE-1. Real-time Information
  - Req-CS-043 Tracking CS vehicle operations
  - Req-CS-043.1 Track SDS Performance
  - Req-CS-055 CS Trip Monitor Management
  - Req-CS-055.1 SDS Trip Monitor Management
  - Req-CTP-045 Transit and mobility service status information
- UN-E-TE-9. Trip Notifications
  - Req-CS-041 SDS User Interface Channels
  - Req-CS-041.1 SDS UI Channel - in-vehicle status audio
  - Req-CS-041.2 SDS UI Channel - in-vehicle status visual
  - Req-CS-041.3 SDS UI Channel - in-vehicle situational awareness audio/visual
  - Req-CS-041.7 SDS UI Channel - External announcements and visual cues
  - Req-CS-041.8 SDS UI Channel - Connection to CTP mobile app
  - Req-CS-042 Communicate SDS Status
  - Req-CS-056 Update CTP on Trip Management
  - Req-CS-056.1 SDS Update CTP on Trip Management
- UN-E-TE-10. Notification Preferences
  - Req-CTP-063 Trip notification preferences
- UN-E-TE-11. Notification and Alert Priority
  - Req-CS-054 Emergency Communications to Passengers
- UN-S-SO-14. Safety of Services
  - Req-CS-015 Passenger Communication Equipment

2.2.12 ET-12 SDS Accessibility Support Technologies

Subsystem: Community Shuttle SDS

Description: SDS vehicles can enhance mobility for all, but only if accessibility and inclusivity are integrated into the design from the outset. Specifically, the SDS need to address safety and accessibility needs for older adults and people with disabilities. The ADA vehicle guidelines do not specifically address SDS but may be applicable or informative to certain types of SDS vehicles. Key accessibility considerations for SDS include boarding/alighting and Accessibility Securement Technology (clearance and seating/securement). Detecting the operations and state (e.g., open, closed, secured, etc.) of the support technologies are described in ET-10. This section specifically details the automated operation of the accessible support technologies.

ET-12.1 Boarding/Alighting - Under the ADA guidelines, vehicles must provide accessible boarding and alighting through either a ramp or bridge plate, lift, or level boarding. Level boarding is the best way to provide access where vehicle floor heights can be coordinated with boarding platforms. “Kneeling” vehicles with automated self-adjusting ride heights could achieve level boarding at various boarding platforms. Ramps (with slopes no greater than 1:6) are an alternative option. Lifts are not a preferred assistive technology for boarding and alighting SDS because of the vehicle low chassis height, their bulkiness, and slow deployment times.

ET-12.2 Accessibility Securement Technology- The second set of technologies address automated securement of wheelchairs. Various attempts at independent wheelchair securement are underway, but none have been widely integrated into SDS. For example, the universal docking interface geometry features an anchorage system in the vehicle that can be used with any wheelchair equipped with the attach mechanism. In addition, Q’Straint offers a semi-automated independent wheelchair securement system, but the system requires individuals to ride backwards, and research findings indicate some design challenges for scooter users.

To support wheelchair access, SDS doorways must open to a clear width of at least 32 inches and have a contrasting color stripe along the bottom that marks the edge of the doorway.[2]. A minimum vertical clearance of 56 inches is required for smaller vehicles, and up to 68 inches for larger vehicles. With respect to maneuvering clearances and seating, the ADA guidelines specify sufficient clearances that allow passengers using wheelchairs and power chairs to proceed from vehicle entry to designated wheelchair spaces, position for securement within the space, and exit the vehicle. In addition, wheelchair spaces must be at least 30 inches wide and 48 inches long.

Integration: Automated operations of door(s), ramps, and securement systems will be integrated in order to support the safe boarding, securement, riding and alighting of passengers. (Readiness of equipment monitoring is described in ET-10.) As an example, ramps will be deployed after the door is opened, and transport will begin after passengers are secured properly in the vehicle.

Procurement: The acquisition of the SDS will be gained through procurement; however, no commercially available SDS currently provides both accessible boarding and independent wheelchair securement. Alternative technologies that are currently implemented in most transit vehicles could be retrofitted to support many of these functions if the desired technologies are not available in a turnkey ADS.

[2] U.S. Access Board. (July 2021). Inclusive Design of Autonomous Vehicles: A Public Dialogue Summary Report. Retrieved from https://www.access-board.gov/files/usab-av-forum-summary-report.pdf (see appendix B TR-4)

Traceability of User Need(s) and System Requirements:

- UN-E-TP-9. Trip Accessibility/Compatibility
  - Req-CS-89 Accessible Emergency Exits
- UN-E-TP-10. Assistive Technology Compatibility
  - Req-CTP-041 Assistive Technology Compatibility
  - Req-Sy-018 Accessible Vehicles
- UN-E-TE-2. Mobility Devices Access
  - Req-CS-008 Ramp / Lift
  - Req-CS-009 Wheelchair Securement
  - Req-CS-041 SDS User Interface Channels
  - Req-CS-041.8 SDS UI Channel - Connection to CTP mobile app
  - Req-CS-042 Communicate SDS Status
  - Req-Sy-005 Vehicle Accessibility Information Collection

2.2.13 ET-13 SDS Operations Support Technology

Subsystem: SOC and the SDS.

Description: The operations support technology refers to technologies needed to support the operations of the SDS. Included within this category are technologies to:

> **ET-13.1 ODD Determination technologies** - check whether a given driving environment meets the constraints of the SDS ODD
>
> **ET-13.2 Traffic Incident Management technologies** - re-route the SDS during major traffic accidents and incidents
>
> **ET-13.3 Remote Monitoring Technologies** - remote monitoring of the SDS vehicle operations. (Remote monitoring functions of the comfort of the passengers are described in ET-10)

Confirming the ODD will require the deployment of sensors for weather, lighting, connectivity, etc., along with decision support algorithms to make the determination. Technologies for traffic incident management and re-routing are quire mature and have been in use as part of ITS deployment for several years already.

Integration: The operations support technologies will need to be fully integrated with the ADS turnkey system including SDS and SOC operations, communications, and control.

Procurement: Technologies for SDS operations support will be procured in a turnkey system integrated with the SDS.

Traceability of User Need(s) and System Requirements:

- UN-S-SO-5. Reporting Issues

  - Req-CS-88 Report health status to CTP
  - Req-CS-88.1 Report SDS Operating Status to CTP
  - Req-Sy-036 CS Health Status Communications Action to the CTP
- UN-S-SO-14. Safety of Services
  - Req-CS-001 Manual and Autonomous Driving
  - Req-CS-013 Multiple Redundant Communication Radios
  - Req-CS-014 Multiple and Redundant Sensor Systems for Perception and Localization
  - Req-CS-014.1 LIDAR Sensor
  - Req-CS-014.2 RADAR Sensor
  - Req-CS-014.3 Camera-Centric Computer Vision
  - Req-CS-014.4 Inertial Measurement Unit
  - Req-CS-014.5 Localization
  - Req-CS-016 Accessible Emergency Button
  - Req-CS-016.1 Emergency stop button misusage
  - Req-CS-017 Onboard Persistent Storage
  - Req-CS-020 Alert Steward of Degraded Communications
  - Req-CS-022 Incident Management due to Degraded Health
  - Req-CS-024 Detect, classify, measure and Interpret Objects
  - Req-CS-024.1 Detect Vehicles
  - Req-CS-024.2 Detect Pedestrians
  - Req-CS-024.3 Classify Objects
  - Req-CS-025 Motion Planning Algorithm
  - Req-CS-026 Operations in Mixed traffic
  - Req-CS-026.1 ODD Rule Set Compliance
  - Req-CS-026.2 Operational Specifications
  - Req-CS-026.3 Driving During Inclement Weather
  - Req-CS-026.4 Avoid Conflicts with Other Vehicles
  - Req-CS-026.5 Avoid Conflicts with Pedestrians'
  - Req-CS-026.6 Avoid Fixed Objects
  - Req-CS-026.7 Avoid Moving Objects
  - Req-CS-026.8 Navigate with Minimum Clearance
  - Req-CS-053 Monitor Passenger Safety
  - Req-CS-060 Low Speed Shuttle
  - Req-CS-91 External/Internal Monitoring
- UN-S-SO-17. Disruptions to the system

  - Req-CS-028 Emergency Stop Actions
- UN-S-BO-6. Operations Reports
  - Req-CS-080 Monitor CS travel anomalies
  - Req-CS-080.1 Monitor SDS travel anomalies
  - Req-Sy-032 Mode of Operation – Normal
  - Req-Sy-033 Mode of Operation – Degraded
  - Req-Sy-034 Mode of Operation – Failure
- UN-S-BO-12. Emergency Report
  - Req-CS-052 CS Notify EMS
  - Req-CS-052.1 CS SDS Notify EMS

2.2.14 ET-14 SDS Fleet Management Technology

Subsystem: Community Shuttle SOC

Description: The fleet management technology includes fleet vehicle schedule, routing, dispatch and monitoring (tracking and performance) as well as operator (or steward) scheduling and management. While the HDS vehicles will use NFTA fleet management technologies (e.g., for their PAL vehicles see ET-2) to manage the vehicles, operators and dispatch, the SDS fleet management will be procured as part of the turnkey SOC/SDS system.

The fleet management functionality includes managing the fleet of SDS vehicles which includes:

- Monitoring operations and maintenance of vehicles
- Tracking vehicle while in operations
- Scheduling and dispatching vehicles (and stewards)
- Generating routes (that conform to ODD) for passenger pickup and dropoff
- Updating SDS routing based on new and cancelled reservations
- Managing reservations (including interacting with CTP to provide service availability based on user preferences/abilities and available seats, date/time, confirm reservations, receive and process cancellations) and generating estimated arrival (at pickup and dropoff points) information for CTP to disseminate to the traveler (see ET-3)

Integration: The fleet management modules will need to be a turnkey system which is closely tied to the SDS both for technical and non-technical reasons. To that end, we expect that the only integration points will be the reservation APIs and real time status information. The other conditions (e.g., multiple SDS vehicles, and SDD network and conditions) should be configurable for the BNMC campus and surrounding communities.

Procurement: The SDS fleet management procured with the SDS procurement.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-1. Spontaneous Trip
  - Req-CS-036 On-Demand Routing and Dispatch
  - Req-CS-036.1 SDS on-demand routing and Dispatch
- UN-E-TP-2. Coverage
  - Req-Sy-012.1 CS Response Time
- UN-E-TP-12. Shuttle Trip Booking and Reservation
  - Req-CS-040 Validate Reservation
  - Req-CS-040.1 Validate SDS Reservation
- UN-E-TE-1. Real-time Information
  - Req-CS-043 Tracking CS vehicle operations
  - Req-CS-043.1 Track SDS Performance
  - Req-CS-049 Mobility Provider Routing Management
  - Req-CS-049.1 SDS Scheduling and Routing
  - Req-CS-055 CS Trip Monitor Management
  - Req-CS-055.1 SDS Trip Monitor Management
- UN-S-SO-8. Data Management
  - Req-CS-082 CS Operational Performance Data Collection
  - Req-CS-082.1 SDS Operational Performance
  - Req-CS-083 Mobility Provider Trip Reporting
  - Req-CS-083.1 SDS Trip Reporting
- UN-S-BO-6. Operations Reports
  - Req-CS-080 Monitor CS travel anomalies
  - Req-CS-080.1 Monitor SDS travel anomalies

2.2.15 ET-15 PED-X technology at signal controllers

Subsystem: Smart Infrastructure (signal controller gateway).

Description: The two intersections identified for deployment of the pedestrian signal request (PED-X) technology are of different vintages. Regardless, they both support NTCIP standards.

- Ellicott St. & High St – this intersection uses a McCain Model 2070 signal controller that is about 10 years old. Implementation of a signal controller gateway will require that the intersection be retrofitted with a transceiver that can receive and transmit the hands-free PED-X request and forward the request to the actuator. There are tools like MioVision (currently deployed by NYSDOT) that access phase information, detect and confirm vulnerable road users and vehicles in the intersection, and implement NTCIP standards based interfaces to the controller (e.g., NTCIP 1201 Global Objects and 1202 Object Definitions for Actuated Signal Controller Units). These have been deployed throughout

NY State and would require software modification and either local communications channels to a mobile phone communication protocol, or center to center communications from the CTP to the device controller.

- Main St. & Best St – a new signal system is in the process of being specified and designed for this intersection. The Buffalo ITS4US project requirements including use of NTCIP standards will be incorporated into the equipment requirements.

Per the discussion for implementing the interaction between the CTP and the signal system (see Section 2.2.5 ET-5 Mobile Pedestrian Crossing Technology Interface), the controller gateway needs to interface with a mobile app through a communications channels such as Bluetooth, WiFi, or other communication technology and then serve as a Priority Request Server (as defined by the NTCIP 1211). Additionally, security policies (including physical, data and cyber protections) will be required by the equipment. The center-to-center approach is more secure and more reliable than a local implementation.

Integration: Vendor modules exist that implement the NTCIP standards with compatible controller; these are mature technologies, and the functions are well tested. Integration with older technologies may require customization and additional development. The critical impact is ensuring that the hands-free actualization does not affect normal operation modes.

Procurement: The equipment to provide and install the gateway between the mobile app and PED-X will be procured, and the vendor will be engaged to configure the system to apply the PED-X use case.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-8. Easy to Use and Flexible App
  - Req-CTP-025 End-User Driven User Experience
  - Req-CTP-026 Communications Channels
  - Req-CTP-027 On-line / off-line data usage and tracking
- UN-E-TP-10. Assistive Technology Compatibility
  - Req-CTP-041 Assistive Technology Compatibility
- UN-E-TE-6. Traveler Guidance
  - Req-CTP-048 Sidewalk Data features
- UN-E-TE-8. Safety
  - Req-CTP-050 Geolocate traveler near intersection
  - Req-CTP-051 Generate PED-X request message
  - Req-CTP-052 Transmit PED-X request message
  - Req-CTP-053 Trusted connection for Ped-X actuation
  - Req-CTP-054 Generate and transmit PED-X request cancel message
  - Req-CTP-055 Generate and transmit PED-X request clear message
  - Req-CTP-056 CTP countdown
  - Req-SI-007 PED-X Status Message

- UN-E-TE-9. Trip Notifications
  - Req-CTP-060 Trip Notification Triggers
- UN-E-TE-10. Notification Preferences
  - Req-CTP-063 Trip notification preferences
- UN-E-TE-11. Notification and Alert Priority
  - Req-CTP-064 Notification and Alert Priority
  - Req-Sy-012.3 CTP Notification Transmission Response Time
- UN-S-SO-2. Intersection Movement
  - Req-CTP-057 PED-X Request Message
  - Req-CTP-058 PED-X Request Cancel Message
  - Req-CTP-059 PED-X Request Clear Message
  - Req-CTP-085 CTP ingestion of traffic signal control operation data
  - Req-SI-027 Transmit Time to Cross (Don't Walk)
- UN-S-SO-3. Wayfinding Infrastructure integration
  - Req-CTP-110 Transmit to Traveler Time to Cross (Don't Walk)
  - Req-CTP-110.1 Transmit to Traveler Time to Cross (Don't Walk) -- Clock Time Synchronization
  - Req-CTP-110.2 Transmit to Traveler Time to Cross (Don't Walk) -- Countdown
  - Req-CTP-111 Monitor for PED-X connectivity
  - Req-CTP-112 Alert Lack of communications for PED-X connectivity
  - Req-CTP-113 PED-X anomalies
  - Req-CTP-114 Alert Traveler to PED-X anomalies
  - Req-SI-001 PED-X Gateway
  - Req-SI-002 PED-X Gateway operation
  - Req-SI-003 Receive PED-X request message
  - Req-SI-004 Log PED-X request
  - Req-SI-005 Forward PED-X request
  - Req-SI-006 Send PED-X status
- UN-S-SO-14. Safety of Services
  - Req-CTP-061 Trip Notification of Trip Anomalies
- UN-S-SO-15. Location Accuracy
  - Req-CTP-101 Tune location settings
- UN-S-SO-16. Accuracy of Information Services
  - Req-CTP-102 Test for accuracy

2.2.16 ET-16 PROW data collection technology and tools

Subsystem: External data provision.

Description: To augment features and attributes in the OSM dataset, additional information on the public right of ways, indoor pathways, and parking facilities will need to be collected. Off the shelf tools exist to collect the information including ones demonstrated by Georgia Institute of Technology (GA Tech), University of Washington / Seattle (UW), and USDOT Accessible Transportation Technologies Research Initiative (ATTRI) wayfinding and navigation projects. Both GA Tech and UW deploy tools that will be compatible with the OTP, the core routing engine used by the CTP. Once the features and attributes are fully integrated with OSM, only the optimization algorithms for assigning impedances to the network graph edges and nodes will be needed (see ET-1, Section 3.2.1).

Integration: No integration needed.

Procurement: Procure a sidewalk mapping tool.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-7 Integrated Data Provision
  - Req-CTP-021 Trip Planning Data validation and processing
  - Req-CTP-022 Reference transportation network
- UN-E-TE-5. Pick-up and Drop-off Zones
  - Req-CS-066 Pickup / Dropoff locations
- UN-E-TE-6. Traveler Guidance
  - Req-CTP-048 Sidewalk Data features
- UN-E-TE-8. Safety
  - Req-CTP-052 Transmit PED-X request message
  - Req-CTP-053 Trusted connection for Ped-X actuation
- UN-E-TE-9. Trip Notifications
  - Req-CS-056 Update CTP on Trip Management
  - Req-CS-056.1 SDS Update CTP on Trip Management
  - Req-CS-056.2 HDS Update CTP on Trip Management
  - Req-CS-056.3 PAL DIRECT Update CTP on Trip Management
- UN-E-TS-8. Crowdsourced Data
  - Req-CTP-080 Traveler feedback form
  - Req-CTP-081 CTP ingestion of feedback
- UN-S-SO-1. Travel Impact Info Integration
  - Req-CTP-084 CTP ingestion of event datasets
- UN-S-SO-2. Intersection Movement
  - Req-CTP-085 CTP ingestion of traffic signal control operation data

  - Req-SI-027 Transmit Time to Cross (Don't Walk)
- UN-S-SO-3. Wayfinding Infrastructure Integration
  - Req-CTP-111 Monitor for PED-X connectivity
- UN-S-SO-14. Safety of Services
  - Req-CS-068 Pick-up, Drop-off location occupied
- UN-S-SO-16. Accuracy of Information Services
  - Req-CTP-102 Test for accuracy

2.2.17 ET-17 Conveyance status reporting and collection technology

Subsystem: Smart Infrastructure (facility conveyance).

Description: In providing navigation directions to persons needing a elevator or escalator, the CTP requires information about the operational status of these vertical conveyance (elevator, escalators, stairs) to plan the trip segment. Elevator and escalator status specifically operational status (operating, maintenance), and other dynamic information (e.g., operating direction, floor) may be published and used by third party applications such as mobile apps or remoting monitoring systems. Each facility (even within a facility) may support more than one conveyance manufacturer product. Because there are no open specifications or standards promulgated that support the information provision, the adaptation will need to be custom.

Integration: A set of APIs from elevator and escalator monitoring tools will need to be ingested by the CTP to support elevator / escalator status. To date, the NFTA generates a manual list that is ingested by downstream systems to publish light rail station conveyance status. Other facilities owners may be included during Phases 2 and 3 depending on their conveyance functionality.

Procurement: The CTP will modify its existing code to ingest a manual list or APIs from facility assets.

Traceability of User Need(s) and System Requirements:

- UN-E-TP-7. Integrated Data Provision
  - Req-CTP-021 Trip Planning Data validation and processing
  - Req-CTP-022 Reference transportation network
- UN-S-SO-1. Travel Impact Info Integration
  - Req-CTP-084 CTP ingestion of event datasets

2.2.18 ET-18 Transportation Information Hub (TIH) Integration with CTP

Subsystems: Smart Infrastructure (TIH)

Description: The Transportation Information Hub (TIH) is a hardened, secure and web-based version of the CTP web application. Using a commercial, ADA compliant hardware device, the TIH (aka kiosk) will be deployed at strategic locations throughout the project’s study area. The TIH will provide users, who do not own a smart phone, with an alternate way to access all the services provided by the CTP including trip planning, booking, setting up accounts and profiles. However, some functions may be restricted based on location and stakeholder needs. The CTP presentation will comply with Web Content Accessibility Guidelines (WCAG 2.1) accessibility features (including the TIH).

Integration: The TIH will be designed to provide a user interface to the CTP system. Since the CTP is API driven (using representational state transfer (REST) and GraphQL APIs [http://docs.opentripplanner.org/en/latest/]), the information flows can be accessed and rendered on multiple end devices including mobile apps, mobile websites, and web clients (including kiosks, such as the one in Figure 4). The majority of the APIs will not be altered, they will be expanded in the types of information they include. Other APIs will be updated and expanded. And several new features will be added including booking CS services. There are dozens of deployments throughout the U.S. and internationally of these APIs using different presentation methods. Some of the new features such as CS booking functions will be added and verified for accessibility, including for people with visual disabilities.

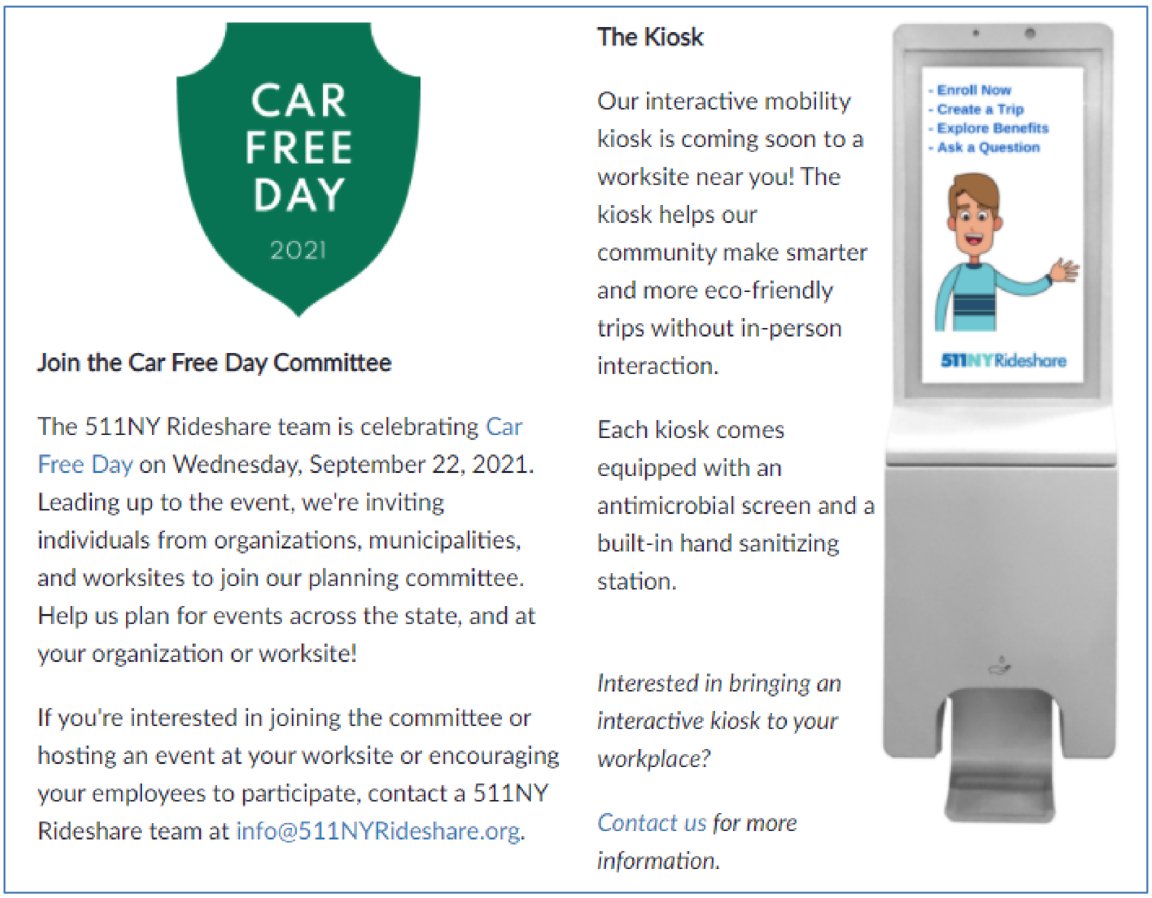

Figure 4. 511NY Rideshare kiosk using 511NY Trip Planner (OTP API driven).
Source: 511NY Rideshare Program, ICF.

Procurement: The TIH hardware will be acquired through procurement and will include specifications that the device shall be ADA compliant, secure (physical, communications and data), and compatible with WCAG 2.1. Configuration of the TIH will be conducted during the installation process and in coordination with the facility owner (who will provide power and internet access).

Traceability of User Need(s) and System Requirements:

- UN-E-TP-8. Easy to Use and Flexible App
    - Req-CTP-024 Accessibility Feature Compliance
    - Req-CTP-026 Communications Channels
- UN-E-TS-4. Low/non-Smartphone Accessibility
    - Req-CTP-027 On-line / off-line data usage and tracking
- UN-S-SO-6. Offline Use
    - Req-SI-020 TIH touch model
    - Req-SI-021 TIH talking touch model
    - Req-SI-022 TIH touch model language selection
    - Req-SI-023 TIH touch model content configuration
    - Req-SI-024 TIH CTP and Touch Model operations
    - Req-SI-028 Public kiosks
- UN-S-SO-9. Hardware characteristics
    - Req-SI-030 SI durability

3 Technology Readiness Level (TRL)

Using the framework documented in Section 2.1, a TRL is assigned to each ET item identified in Section 2.2. The approach to assigning a TRL is described in Section 3.1, whereas Section 3.2 lists each ET item, TRL and justification.

3.1 TRL Assessment Process

The TRL Assessment Process reviews each technology and applies the criteria (responses to questions) described in the FHWA Guidebook (see Table 1) to determine the readiness level. The assessment was conducted by groups of end users including operator and partner stakeholders who plan, develop, operate and maintain these technologies and technology experts. The materials they use to conduct the assessment comes from the following:

- Expert experience from panel members who have implemented the technology or interaction between technologies, or who have implemented similar technologies;
- Market scan of products or technologies that meet the requirements specified for the system solution (or use case);
- Interviews with outside experts who have demonstrated, piloted, and/or deployed the technology, similar technology, or interaction between technologies; and
- Literature review related to demonstration, pilot or operational deployment of the technology or similar technology.

The panel used this evidence to answer the questions in the Criteria column of Table 1.

Table 1. TRL Assessment Criteria (source: FHWA Guidebook).

TRL	TRL Name	Criteria
1	Basic principles and research	• Do basic scientific principles support the concept? • Has the technology development methodology or approach been developed?
2	Application formulated	• Are potential system applications identified? • Are system components and the user interface at least partly described? • Do preliminary analyses or experiments confirm that the application might meet the user need?

TRL	TRL Name	Criteria
3	Proof of concept	• Are system performance metrics established? • Is system feasibility fully established? • Do experiments or modeling and simulation validate performance predictions of system capability? • Does the technology address a need or introduce an innovation in the field of transportation?
4	Components validated in laboratory	• Are end-user requirements documented? • Does a plausible draft integration plan exist, and is component compatibility demonstrated? • Were individual components successfully tested in a laboratory environment (a fully controlled test environment where a limited number of critical functions are tested)?
5	Integrated components demonstrated in laboratory environment	• Are external and internal system interfaces documented? • Are target and minimum operational requirements developed? • Is component integration demonstrated in a laboratory environment (i.e., fully controlled setting)?
6	Prototype demonstrated in relevant environment	• Is the operational environment (i.e., user community, physical environment, and input data characteristics, as appropriate) fully known? • Was the prototype tested in a realistic and relevant environment outside the laboratory? • Does the prototype satisfy all operational requirements when confronted with realistic problems?
7	Prototype demonstrated in operational environment	• Are available components representative of production components? • Is the fully integrated prototype demonstrated in an operational environment (i.e., real-world conditions, including the user community)? • Are all interfaces tested individually under stressed and anomalous conditions?
8	Technology proven in operational environment	• Are all system components form-, fit-, and function-compatible with each other and with the operational environment? • Is the technology proven in an operational environment (i.e., meets target performance measures)? • Was a rigorous test and evaluation process completed successfully? • Does the technology meet its stated purpose and functionality as designed?
9	Technology refined and adopted	• Is the technology deployed in its intended operational environment? • Is information about the technology disseminated to the user community? • Is the technology adopted by the user community?

3.2 TRL Ratings for Inventoried Enabling Technologies

Ratings for ET items are identified in this section. Each ET includes a TRL level and justification for the assigned level. The justification is assigned based on the Assessment Readiness Process described in Section 3.1.

3.2.1 ET-1 Technologies for Integration of Public Right of Way (PROW) Features TRL 7

The OTP has tools that enable system developer to integrate new static and real time information when generating a modal network that includes sidewalk, transit, or bicycle network edges. The OTP routing tool applies an optimization algorithm to generate paths through a graph with weighted edges and nodes. For example, the weightier the traversal through an edge (e.g., broken sidewalk) or node (e.g., intersection without a curb cut), the less optimal the path in the trip plan. Traversal through the graph generates the optimized trip segments that produce the trip plan. The edge and node impedances are based on the ease or challenges designated by the PROW features (attributes and conditions), and the traveler preferences and their assistive devices. The PROW features provide information to assign weights to the edges and nodes. The graph data structures used by the OTP are configurable which enable integrating new data sources into the current CTP functions. The technology will be leveraged to extend the network features and attributes. In addition, the developers will need to develop algorithms to generate edge/node impedances (weights) based on traveler's preferences and abilities. The system will require rigorous testing to ensure complete success. Table 2 summarizes the TRL for ET-1.

Table 2. TRL Rating for ET-1.

TRL	TRL Name	Justification Summary
7	Prototype demonstrated in operational environment	• The PROW sidewalk feature collection technology has been tested and currently operational using different modal pathways (e.g., roads, bicycle lanes, transit alignments in Seattle (UW), metro Atlanta (GA Tech), and ATTRI AbleLink, Pathways Accessible Solutions and TRAX Projects. • The OSM has the capability to integrate additional PROW features, attributes and conditions into their data structures (that are represented as a graph). • The OTP routing engine does not need to change, however, the logic to select the appropriate graph impedances to apply to traveler preferences will be required. • Testing is required to define, test, and tune the impedance algorithms against combinations of traveler preferences and abilities.

3.2.2 ET-2 PAL and HDS Trip Booking Transaction Technology Interface TRL 7

The system developer has experience with integrating third party applications that require sharing account information and providing reservations transactions. In addition, it includes functions for ingesting real time trip notifications and provisioning them as notifications to travelers. The data structures for real time information are currently available and have been implemented in other operational environments. The specific transactions have not been deployed, although equivalent message sets have been implemented. The assessment was ranked at a TRL 7 because the team anticipates that rigorous testing and evaluation process will be necessary to ensure complete success. Table 3 summarizes the TRL for ET-2.

Table 3. TRL Rating for ET-2.

TRL	TRL Name	Justification Summary
7	Prototype demonstrated in operational environment	• The reservation technology has been tested and currently operational using different vendor reservations APIs (for availability, confirmation, cancellation, and update). Additional verification and development will be needed to integrate the NFTA vendor APIs to integrate with the CTP. • The real time tracking and information provisioning technology has been tested and currently operational using GTFS realtime. The accuracy of the reporting system will need to be verified during system testing.

3.2.3 ET-3 Community Shuttle Trip Booking Transaction Technology Interface TRL 5

The technology impact is derived by the lack of information on the effort needed to implement the services. Although the specific reservations services and real time status information have not yet been acquired, the interface technology – message formats, orchestration, and internal processing is well established and supported by several existing and emerging standards. There are several operational trip booking technologies that may be used. We expect that the HDS will use PAL DIRECT, already available as an API transaction set. Other off-the-shelf or vendor booking API transaction sets are available to use for any of the CS services whether on-demand, microtransit or carpooling services including tools developed for web or mobile apps by Buffalo team members. The TRL of 5 is due to the unknown vendor. We expect the maturity level will rise when the booking technology(ies) are selected in Phase 2.

The rating will be revisited once the SOC reservation system and interface procedures are selected. Table 4 summarizes the TRL for ET-3.

Table 4. TRL Rating for ET-3.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• The reservation technology has been tested and currently operational using different vendor reservations APIs (for availability, confirmation, cancellation and update). Verification and development will be needed to integrate an *unknown vendor's* APIs to integrate with the CTP. Also, many SDS vendors have their own fleet management

		software that could be integrated with the CTP. • It is quite likely that, by the time of phase 2 of the project, GTFS will be mature enough to use, or that there would be other APIs that support the work. For example, CEN (European standards organization) is in the process of publishing a survey of all the MaaS platforms that have deployed reservation APIs. • The real time tracking and information provisioning technology has been tested and currently operational using GTFS realtime. The accuracy of the reporting system will need to be verified during system testing.

3.2.4 ET-4 Navigation Technology Integration with Smart Signs TRL 7

The integration of smart signs and the CTP relies on mature technologies that are integrated together. Integration with NFC tags that provide destination confirmation have already been implemented in pilot projects in the indoor environment. The project team will leverage the research pilot functions and apply them to provide notification alerts and information in the CTP mobile app. The BLE beacons have also been implemented in other pilot projects and currently deployed in airports and other indoor and outdoor facilities (See Appendix B, TR-3 publications). The team will work with the BLE product APIs to build the capability into the CTP mobile app. Table 5 summarizes the TRL for ET-4.

Table 5. TRL Rating for ET-4.

TRL	TRL Name	Justification Summary
7	Prototype demonstrated in operational environment	• The technology has been proven in similar use cases as are envisioned in the Buffalo ITS4US project. • The integration with mobile app and sign technologies have been prototyped in similar environments. • Existing APIs are available to integrate the technologies together. • Sign technology packaging allow deployment of these technologies into the range of environments to be deployed. • Robust testing will be required to adapt these technologies into the project solution in particular, positioning and tuning of sign technology will be critical for human machine interaction.

3.2.5 ET-5 Mobile Ped Crossing Technology Interface TRL 5

This implementation has been implemented in several locations. Many of them use CV infrastructure including the CV Pilots in Tampa and NYC and ATTRI Safe Intersection Crossing (see Appendix B, TR-2 publications). The NYC CV Pilot and ATTRI Safe Intersection Project used

MapData messages and signal phase and timing messages to identify the crosswalk and phase signal request. This implementation will apply the lessons learned from these pilots but use the signal phase data (gleaned from signal phasing charts) to identify the specific crosswalk for which service is requested and service the information through a center-to-center information flow. In addition, improvements to ET-6 Mobile App Positioning and Orientation Technology will also support location and orientation accuracy. The initial approach to requesting walk service will use NTCIP 1211 Signal Control and Prioritization messages, which is used for transit signal priority and emergency vehicle pre-emption. Many traffic signal systems are NTCIP compatible, and as such, the technology has been applied by many signal vendor systems. The CTP mobile app will require software modification to monitor pedestrian travel, trigger and respond to the appropriate NTCIP messages. Table 6 summarizes the TRL for ET-5.

Table 6. TRL Rating for ET-5.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• Similar implementations of the pedestrian crossing request application have been implemented and been somewhat successful. There are still positional and orientation accuracy issues that impact traveler safety. Because of the criticality of these issues, a TRL of 5 is selected here. • Signal systems that actuate the request and signal service use the technology envisioned by the use case. There are alternative approaches to implementing the request if the NTCIP 1211 message set are not effective. • CTP has interfaced (broker real time messages) with similar 3rd party systems. • Robust testing will be required to adapt these technologies into the project solution in particular, accurate positioning, message latency, user interface to show walk and don't walk signals.

3.2.6 ET-6 Mobile App Positioning and Orientation Technology TRL 5

Several approaches have been applied to increase the accuracy of mobile app location and orientation tracking. These include location referencing stations, aiding sensors attached to the mobile device, high location, and navigation filter settings on the phone. Each has its drawbacks including cost, infrastructure deployment costs, handset battery consumption, among others (see Appendix B, TR-1 publications). Alternative solutions will be considered as part of Phase 2 design and prototype. Table 7 summarizes the TRL for ET-6.

Table 7. TRL Rating for ET-6.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• The technology has been proven in similar applications as demonstrated in existing pilots and operational environments. However, because the accuracy of positioning and orientation technologies have a direct impact on traveler safety, a TRL of 5 is selected here.

		• Technology adoption may exceed the resources of the target populations which will require additional trade-off and evaluation.

3.2.7 ET-7 Mobile Accessibility Technology TRL 8

Every smart phone operating system includes accessibility tools that can be leveraged to provide mobile app accessibility. The operating system vendors provide accessibility guidelines on how best to apply these native features. Published best practices identify testing to the latest Web Content Accessibility Guidelines (WCAG) using persona-based test cases (to test for multiple preferences and abilities). The testing protocols can be procured off the shelf or by organizations with significant experience. In addition, using an Agile development process, end-users with experience testing a variety of native features will be recruited to test the beta version of the software. Table 8 summarizes the TRL for ET-7.

Table 8. TRL Rating for ET-7.

TRL	TRL Name	Justification Summary
8	Technology proven in operational environment	• Google and Apple provide accessibility guidelines on how to best apply native accessibility features to mobile apps. • WCAG 2.1 (and forthcoming 2.2) includes provisions and a checklist for applying accessibility features. These have test procedures for apply robust testing of the app. • Additional features will be reviewed and piloted through the Agile development process by users and testing of key persona will be applied.

3.2.8 ET-8 Wearables and Interfaces Technology TRL 6

Development of smart watch apps, though new, uses software development kits that are similar to mobile apps. There is industry experience in deploying travel apps, notification message and vibrations, and other functions and characteristics envisioned for the Buffalo ITS4US project. The technologies have not been used in a widespread, commercial environment for the Buffalo target populations. To that end, the rating is assigned a TRL 6: prototype demonstrated in relevant environment (but not with relevant population). Table 9 summarizes the TRL for ET-8.

Nonetheless, technology implementations are growing. In particular, the following research indicates that a growing body of reusable code (SDK) and knowledge about wearables will be available over the next few years. The research includes the following:

- WatchOS apps for Apple Watch can be embedded inside a traditional phone app. If a user with a watch installs the mobile app, the embedded watch version will automatically transfer to the Apple Watch when it is in Bluetooth range. Google has abandoned the ability to auto-install with Android Wear 2.0 watches, but users will receive an automatic notification on their watch to install the companion watch app.

- Since Apple's watchOS version 6, it has been possible to release watch apps that work independently from a phone, supported by WiFi or Long Term Evolution (LTE) cellular connections. This is also possible with Android Wear-based watches, and Google discourages the creation of apps that are dependent on a phone. For any cooperation with an external device, Google strongly recommend that Android Wear apps are compatible with both iOS and Android phones.

- Push notifications to the phone app will be received by the watch app, as long as it is in Bluetooth range of the phone. The phone can also send notifications to the watch application, and a server can send push notifications directly to a watch. The notification behavior can be controlled by applications or the user.

- Because of the push for modern wearable devices to work standalone without a companion phone, a watch app must provide geolocation and navigation independently, and consequently can become a less expensive, navigation and wayfinding device for travelers.

Table 9. TRL Rating for ET-8.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• There are implementations of this technology available in the commercial marketplace. The features and functions have been proven and ready to deploy. • With respect to the project's population, the human machine interface the use of the technology is not as well known. Within the agile development process, extensive testing by the target user community will be applied to refine the application and move to define best practices and deploy in the project.

3.2.9 ET-9 – Self-Driving Shuttle (SDS) Automated Driving System (ADS) Technology TRL 6

The development, testing and demonstration of ADS have been the focus of numerous efforts over the last 20 years. In terms of SDS ADS technology, in particular, there are already several models, made by different companies, commercially available. Examples include EasyMile's EZ10 shuttle, Navya's Autonom, Local Motors's Olli, the Polaris-Gem electric vehicle adapted for autonomous driving by Perrone Robotics, shuttles by May Mobility, OptimusRide's shuttles, and vans outfitted for autonomous driving by Waymo. The use of the technology has been demonstrated in several cities both in the United States as well as abroad. Demonstrations included the use of SDS to provide fixed route as well as on-demand service, or using SDS to serve as circulator, feeders to traditional public transit, and to address first- and last- mile challenges. Demonstration locations include Jacksonville, FL, Columbus, OH, Arlington, TX, Doraville, GA, and Las Vegas, NV. Table 10 summarizes the TRL for ET-9.

Table 10. TRL Rating for ET-9.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• SDS ADS technology has been subject to intense R&D, systematic extensive testing, and successful deployment. • An example SDS company, Waymo, has had successful operation in 25 cities, has logged 20 million miles on public roads, along with 20 billion miles in simulation. The software disengagement rate

		averaged only once per 30,000 miles, where either the safety steward temporarily took over, or the software safe operation fail-over instruction had the vehicle pull over. Waymo has been in actual revenue service deployment in Chandler AZ, with trips with no safety steward. • Numerous other SDS companies are also deployed throughout North America and the world. In California alone 28 companies last year reported SDS ADS statistics to the DOT for their operations in the state. • SDSs with ADS operate in well-designed ODD. This mode allows all roads to be carefully planned and mapped for safe operation. Similarly, the Buffalo SDS ODD will be limited to selected roads to be extensively designed and tested for safe operation. • However, because of concerns about operations under inclement weather conditions, a TRL of 6 (as opposed to TRL 7 or 8) is selected here.

3.2.10 ET-10 – SDS In-vehicle Monitoring and Communications Technology TRL 6/8/9

The TRL vary by technology subset as follows:

ET 10.1 – Boarding/Alighting Monitoring Technologies **TRL 6**
ET 10.2 – SDS Cyber/Physical Elements “Health” Monitoring **TRL 8**
ET 10.3 – V2X Communications **TRL 9**

ET-10.1 will be implemented through an adaptation of the existing sensor technologies that detect doors open/closed, seat belts locked, and digital cameras with 3-dimensional vision software. Although the sensor and vision software are tested in similar operational environments, the configuration and integration into the SDS will need to be adapted.

For ET-10.2, the monitoring of the “health” of the cyber elements of a SDS is already implemented in almost all commercially available SDS. Moreover, monitoring the different mechanical and electrical components of a traditional humanly-driven vehicle, including monitoring currently available accessibility support mechanisms such as lifts, is already available on almost all vehicle and transit vehicle models. The only piece that is perhaps missing from existing monitoring systems is the monitoring automated accessibility and wheelchair securement systems that are envisioned to be deployed under the ET-12 technology bundle to support accessibility on SDS.

Finally, for ET-10.3, the communications technology is very mature, proven and already deployed worldwide.

Table 11 through Table 13 summarize the TRLs for ET-10.

Table 11. TRL Rating for ET-10.1.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• Technology will be implemented through an adaptation of a commercially available, mature technology. The only piece that is perhaps missing from existing monitoring systems is monitoring those automated accessibility and wheelchair securement systems that are envisioned to be deployed under ET-12.

Table 12. TRL Rating for ET-10.2.

TRL	TRL Name	Justification Summary
8	Technology proven in operational environment	• Commercially available SDS monitor the “health” of their cyber elements.

Table 13. TRL Rating for ET-10.3.

TRL	TRL Name	Justification Summary
8	Technology refined and adopted	• Technology is very mature, proven, and deployed across the country. Additionally, there are standards in place to ensure conformity. Only issue is that this has not been tested within the scope of this pilot project, hence the 8.

3.2.11 ET-11 – SDS Passenger Information System TRL 5

As mentioned in Section 2.2.11, the SDS passenger information system will be procured as part of the SDS. The procured system is specified to integrate message signs, CCTV, annunciators and more. In addition, the vehicles are specified to deploy an open architecture to support either an OEM (original equipment manufacturer) or after-market passenger information system. These technologies are deployed by transit agencies for their bus and van fleets throughout the US. Passenger information systems, with many of the functionalities envisioned under the ET-11 technologies, are already available on systems quite similar to SDS; for example, automated people movers at airports. Transit agencies deploy the information systems in their microtransit services wherein the information provision is automated and dynamic. In addition, there are efforts by SDS manufactures to add passenger information systems to their shuttles. For example, Local Motors’, the manufacturer of Olli, recently crowdsourced cutting-edge accessibility solutions and developed a non-operational, concept prototype called the Accessible Olli including an avatar that is capable of Sign language for communication. The TRL rating was assigned based on the existence of mature passenger information systems used by transit fleet operators on a variety of vehicles and service offering from buses, rail cars, vans and using fixed, flex, microtransit and on-demand service strategies. Table 14 summarizes the TRL for ET-11

Table 14. TRL Rating for ET-11.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• While passenger information systems, with the full set of functionalities envisioned for this project, are not yet available on all SDS, such systems are already deployed on other transportation systems (e.g., automated people movers at airports). In addition, there are efforts by several SDS manufactures to implement such systems on their shuttles. However, because some desirable functionalities may not have been fully tested, a TRL of 5 is selected here.”

3.2.12 ET-12 – SDS Accessibility Support Technology TRL 5/6

The TRL vary by technology subset as follows:

ET-12.1 - Boarding and Alighting Accessibility Support **TRL 6**
ET-12.2 - Automated wheelchair securement technologies **TRL 5**

For ET-12.1, most SDS models include ramps such as EasyMile’s EZ10, Navya’s Autonom Shuttle and Local Motors’ Olli. If the ramp is automated, its interface is a push button.

For ET-12.2, independent wheelchair securement system implemented in fixed-route vehicle and field-tested. Accessibility design features (i.e., ramp, securement, etc.) have been individually evaluated in different lab-based research studies that include vulnerable populations (e.g., University at Buffalo, University of Michigan).

For both these accessible support technologies, the SDS vendor may need to integrate or retrofit the technologies in the procured system. Table 15 and Table 16 summarize the TRL ratings for ET-12.

Table 15. TRL Rating for ET-12.1.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• EasyMile’s EZ10, Navya’s Autonom Shuttle include ramps using a push button. Other vendors have also retractable wheelchair ramp (e.g., Local Motors’ Olli). The Buffalo project wants an automated system. Automation of the ramp and open/close doors have not yet been implemented. • Ramps for boarding and alighting assistive devices have been individually evaluated in different lab-based research studies that include vulnerable populations (e.g., University at Buffalo, University of Michigan).

Table 16. TRL Rating for ET-12.2.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• Independent wheelchair securement mechanisms have been individually evaluated in different lab-based research studies that include vulnerable populations (e.g., University at Buffalo, University of Michigan). • Independent wheelchair securement system implemented in fixed-route vehicle and field-tested.

3.2.13 ET-13 – SDS Operations Support Technology TRL 5/6/7

The TRL vary by technology subset as follows:

ET-13.1 ODD Compatibility Determination **TRL 6**
ET-13.2 Traffic Incident Management Technology **TRL 7**
ET-13.3 SDS Remote Monitoring Technologies **TRL 5**

ET-13.1 – Confirming a given driving scenario is within the safe ODD of a SDS (i.e., ET-13.1) will need to be based off information collected from various sensors for weather, lighting, connectivity, etc. Those sensors typically can be found onboard almost all commercially available SDS. A simple decision-tree model could then use this information to autonomously make the determination regarding ODD compatibility. Since University of Buffalo has operated an AV on the Univeristy's north campus and demonstrated its operations, the ET-13.1 is thus assigned a TRL of 6 since some development work is needed on the decision-tree model.

ET-13.2 – Technologies for traffic incident management and re-routing are mature and have been in use as part of ITS deployments for several years already including as part of fleet management and traffic operations centers. These technologies are this assigned a TRL of 7.

ET-13.3 – The basic functions for monitoring exist. The control of the vehicle from a remote location has yet to be fully demonstrated although it has been proven in field testing. To that end, this ET is assigned a TRL of 5. These technologies are envisioned for future phases, not for the initial Buffalo deployment (Phase 3).

Table 17, Table 18, and Table 19 summarize the TRL ratings for ET-13.

Table 17. TRL rating for ET-13.1.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• Data needed to determine the compatibility between the driving environment and the SDS ODD are readily available from the sensors onboard a SDS. A decision-tree model still needs to be developed for autonomously determining whether a given driving environment satisfies the SDS ODD.

Table 18. TRL rating for ET-13.2.

TRL	TRL Name	Justification Summary
7	Prototype demonstrated in operational environment	• Technologies for traffic incident management and re-routing functions are mature and have been in use as part of ITS deployment for several years already, and within Traffic Operations Centers, but not within the context of a SDS. • It should be noted, however, that our vision for how traffic incident technologies would work with the SDS is a very basic implementation that would proceed as follows. In case of a traffic incident, the regional TMC (i.e., NITTEC for the Buffalo area) would inform the SOC. SOC would then generate an alternate route for the SDS, using the same logic and algorithm used for scheduling pick-up and drop-off. The SOC would also update the ETA for the SDS. Passengers would be notified about the new ETA's using CTP.

Table 19. TRL rating for ET-13.3.

TRL	TRL Name	Justification Summary
5	Integrated components demonstrated in laboratory environment	• While the technologies needed to implement SDS remote monitoring exist, the concept is yet to be fully demonstrated in a realistic or operational environment.

3.2.14 ET-14 – SDS Fleet Management Technology TRL 7

SDS fleet management technology and models will leverage many of the existing technologies and algorithms that are currently being used in managing fleets of human-driven vehicles and shuttles, a technology that is quite mature and well-proven. Many SDS manufacturers provide their own fleet management technologies for their SDS fleets. Mathematically, the vehicle routing problem with time windows, which is at the core of SDS fleet management technologies is a commercially viable product which can be acquired off-the-shelf. Table 20 summarize the TRL ratings for ET-14.

Table 20. TRL rating for ET-14.

TRL	TRL Name	Justification Summary
7	Technology proven in operational environment	• Several SDS manufactures provide SDS fleet management tools to better manage their SDS functionalities. • SDS fleet management tools leverage many of the existing technologies used to manage human-driven vehicles.

3.2.15 ET-15 PED-X technology at signal controllers TRL 6

There are many third-party software that interface with actuated signal control units. The NTCIP series of standards (e.g., NTCIP 1201 and 1202) includes pedestrian signal actuation in the body of standard objects. The major readiness issue is whether the end-to-end process can be implemented, that is the message flow from request to actuation request, not if an external device can securely interface to request phase changes or detect time to service desired information. The interface between the priority signal generator and the controller is out of scope of this project. That technology is implemented by the City of Buffalo. For the yet to be procured signal system on Main St. & Best St, the technology can be procured to support the NTCIP standards. Because Ellicott St. & High St are legacy technologies, the intersection may not be "ready" for the current technologies that enable the Priority Request Server (PRS) to Coordinator (CO) interfaces. That does not suggest that the technology is not mature, it only suggests that the intersection location may need to be changed to find an appropriate site. If the technical hurdles to retrofit the equipment present an obstacle, an alternative intersection may be selected where the technologies are ready to be deployed. The mobile app interface with the signal request server is discussed in ET-5. Table 21 summarizes the TRL ratings for ET-15.

Table 21. TRL 6 rating for ET-15.

TRL	TRL Name	Justification Summary
6	Prototype demonstrated in relevant environment	• Although the standards that support the signal prioritization are mature and have been implanted with hundreds of signal controllers including ones supported by New York State DOT and the City of Buffalo, the approach has not been successfully and repeatedly applied to end to end or to PED-X request actualization. • The readiness is not on detecting the location of the traveler, rather the provision of the information related to the traveler's path to the CTP so that it can include the appropriate information in the request message to the signal controller. • In addition, the CTP will receive the real-time signal control information in a timely manner then communicate walk and don't walk information to the traveler as they are waiting to cross. Several technology challenges are identified to synchronize timing between the traveler device and signal controller.

3.2.16 ET-16 PROW data collection technology and tools TRL 8

An assumption about the PROW data collection technology tool is that the information will be transformed to an OSM format with common set of attributes and weights per graph edges and nodes prior to being ingested into the OTP. If that is the case the technology is mature and implemented in the operational environment (TRL 9). Adoption of new tags and attributes will require refinement, tailoring, and adjustments to the weighting algorithms. These types of procedures are done whenever OSM adds new tags, which has occurred fairly often over the past few years. Table 22 summarize the TRL ratings for ET-16.

Table 22. TRL rating for ET-16.

TRL	TRL Name	Justification Summary
8	Technology proven in operational environment	• System is proven and technology has been applied in an operational environment for several years. • New features and tags will require some customization, although the adjustments have been for other modes and attributes.

3.2.17 ET-17 Conveyance status reporting and collection technology TRL 7

Facilities do not tend to expose APIs that provide information about elevator or escalator floors and operational status. If they publish an API, the effort to integrate the status would use existing data broker functionality to integrate new data sources. If the systems do not have a published API, signal trapping may need to be embedded into the conveyance system. If that is the case, customized programming would need to be put in place, and an automated procedure to detect operations may not be feasible. Table 23 summarize the TRL ratings for ET-17. The TRL may change depending on the facility(ies) selected to be used in the project.

Table 23. TRL rating for ET-17.

TRL	TRL Name	Justification Summary
7	Prototype demonstrated in operational environment	• In an open architecture environment, with a clear definition of the data provisioned in an API, the CTP will be able to receive and process the information and then disseminate it to travelers opting for the information. • A custom interchange of the API will need to be established, but these are common for any open architecture tool and does not pose significant risk. • Moving forward, the interface will be testing and stressed to reduce latency and ensure reliability between the systems.

3.2.18 ET-18 Transportation Information Hub (TIH) Integration with CTP TRL 8

The technology has been proven in operational environments across the US and internationally. As described by the OTP literature, "[t]his service can be accessed directly via its web API or using a range of Javascript client libraries, including modern reactive modular components targeting mobile platforms" [https://www.opentripplanner.org/]. Since the TIH supports web-services irrespective of the technology presentation, the deployment options extend to kiosk form factors while applying SCAG 2.1 specifications. Several deployments incorporate booking and reservations services including 1-Click implementations using OTP (deployed in Ventura (CA) and Orange County (NY) and Smart Columbus. All three of the US developers of OTP have deployed kiosk and service oriented deployments. Table 24 summarize the TRL ratings for ET-18.

Table 24. TRL rating for ET-18.

TRL	TRL Name	Justification Summary
8	Technology proven in operational environment	• System is proven and technology has been applied in an operational environment for several years. • New features will need to be tested for accessibility.

4 Risk Assessment

The risks posed by the TRL rankings will drive the schedule, development, and costs of deploying and operating these technologies to meet system goals and objectives. Assignment of an impact level and its probability necessitates a mitigation plan. Section 4.1 describes known and anticipated risks, specifically the section inventories technical risks and gaps anticipated in designing, deploying, and operating the technology to meet user needs. Section 4.2 describes mitigation plans for dealing with high impact risks that are identified in the risk inventory.

4.1 Assessing Risk

The risk assessment follows the procedures described in the Project Management Plan (PMP) Section 11. According to the PMP, the risk management process includes steps to identify, analyze, plan, monitor and control (see Figure 5):

- Risk Identification – Identification of the risks that may potentially affect the project and documentation of the characteristics.
- Risk Analysis – Assessment of the potential outcomes on project activities of each identified risk based on qualitative and quantitative evaluations, and prioritization of risks based on anticipated outcomes.
- Response Planning – Development of options and actions to enhance opportunities to manage identified risks and to reduce threats to project objectives.
- Risk Monitoring and Control – Processes to implement developed risk response plans, track risks, monitor residual risks, identify new risks, and evaluate risk process effectiveness.

Figure 5. ICF's Risk Management Approach.
Source: Buffalo, NY ITS4US

Table 27 lists the risk identified for this project. The table includes the following fields:

- **Risk ID:** Uniquely defined for this document but will be updated to a unique ID in the risk register.
- **Enabling Technology:** the identifier for the enabling technology, referenced as ET-n, where n is the unique reference to the technology.

- **Risk Description:** a short description describing the risk and other concerns related to the risk.
- **Impact Level:** the anticipated impact the risk will cause to the system. The criteria used to assign levels include:
  - **Low:** The impact will be limited or minimal and be handled by an alternative design solution.
  - **Medium:** The impact will affect operations or end-user use of a system component, function, or access method. Design or technology alternatives may be applied to avoid the impact.
  - **High:** The impact will affect major operations or end-user use of the system and may impact user safety. Additional equipment or support services will be needed to mitigate the impact on the end-user.

These impact levels correspond to the ones listed on the PMP and the Risk Register, listed below in Table 25.

Table 25. Risk Level Determination Matrix

Impact	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
		Probability				

Based on the risk level determination, risks be categorized as high, medium, and low risk as shown in Table 26:

Table 26. Risk Categorization

Color	Score	Risks
Red	15-25	High
Yellow	5, 8-12	Medium
Green	1-4, 6	Low

Table 27. Risk Assessment for Each Enabling Technology

Risk ID	Enabling Technology	Risk Description	Impact Level
1	ET-9, ET-10, ET-11, ET-12, ET-13, ET-14	Procurement of Turnkey SDS with available features – the aggregate set of technologies needed to support the operations, monitoring, control, maintenance, and passenger accessibility features of the SDS are offered by different ADS vendors. Finding and procuring all the features both in the vehicle and operations center may be challenging.	Medium
2	ET-2, ET-6, ET-17	Coordination with external systems – several of the system require collaborations between project resources and external systems, for example, integrating building conveyance or smart sign data (deployed in private facilities) with the CTP.	Low
3	ET-5, ET-6, ET-7	Understanding Lifecycle Trade-off of using BLE vs. NFC – several technologies are available to improve indoor, outdoor and intersection crossing orientation and navigation functions. Some technologies are better for some scenarios over others. Information still unknown is the identifying the most effective technology to meet the most goals and its total cost of ownership. More details about the risk associated with each technology will be better understood following a technology alternatives analysis.	Low
4	ET-8	Integration of emerging technologies – the deployment and use of wearables is new and emerging. As more people begin to adopt these technologies, their capabilities and uses will expand. This risk consists about whether this trend will become more widespread during the project and its usefulness to meet end-user needs.	Low
5	ET-10.1	In-Vehicle monitoring technologies – the full set of technologies to monitor passenger safety including sensors for door open/closed, seat belt and wheelchair securement may not be available in all ADS shuttle models.	Medium
6	ET-11	SDS Passenger Information System resources – the development of the SDS Passenger Information System will require significant investment of time and resources	Medium
7	ET-12.2	SDS Wheelchair securement – various attempts at independent wheelchair securement are underway, but none have been widely integrated into SDS.	High
8	ET-13.3	SDS Remote Monitoring – while the technologies needed to implement SDS remote monitoring exist, the concept is yet to be fully demonstrated in a realistic or operational environment.	High
9	ET-15	PED-X end-to-end transactions – while the standards exist and the communications technologies are mature, legacy traffic signal systems may not be capable of supporting the needs. In addition, there are challenging, though manageable, technology issues that require design and tailoring.	Medium

4.2 Mitigating Risk

This section describes the risk probability and mitigation plans for high-risk and medium-risk issues from the risk inventory cataloged in Table 27. Table 28 lists the risk-by-Risk ID, assigns a Risk Probability (high, medium or low), and outlines a mitigation strategy to reduce the risk. The risks that fall into this category will be inserted into the project Risk Registry.

The factors that are used to assign risk probability may be identified for a segment of the target end-user population, environmental conditions, or other temporal factors. It should be noted that the mitigation plan applies to technology solution alternatives. There are operational and procedural rules and policies that may mitigate the impact as well (such as suspending service during operations under the conditions). These are designated in the mitigation plan description as a policy alternative. The probability values do not contain percentages of occurrence because an alternative analysis, technology selection and design approaches should be factored into the probability rating. Instead, the Risk Probability levels rely on the occurrence of temporal or persistent external events related to environmental conditions, or technology disruptions / degradation.

- **Low**: temporary occurrence impacting segment of users or partial operations (e.g., environmental conditions and technology disruptions).
- **Medium**: persistent occurrence impacting a segment of users or operations.
- **High**: persistent occurrence impacting all users or critical operational functions (e.g., safety related).

Table 28. High-Impact Risk Mitigation Plans.

Risk ID	Risk Probability	Mitigation Plan
1	Medium	A key requirement in the procurement of the SDS will be that the SDS vendor allows integrating aftermarket technologies with the procured SDS. This will allow for the integration of any needed technologies that are not part of the procured SDS such as those needed to support the operations, monitoring, control, maintenance, and passenger accessibility features of the SDS
5	Low	The requirement for the SDS vendor to support the integration of aftermarket technologies should enable adding any key features that the procured SDS may be missing.
6	Low	Efforts will be made first to identify a turnkey SDS that has as many of the desired features of the Passenger Information System features as possible.
7	Low	The SDS steward will be onboard to secure a wheelchair using the available securement system.
8	Low	The SDS steward will be onboard during the whole duration of the current project. The remote monitoring function is intended to add a second layer of supervision (in addition to the onboard steward). Remote monitoring is designed to further add to the confidence of the user in the safety and security of the system.

9	Medium	Travelers, particularly people with visual disabilities, using the PED-X application will be closely monitored to ensure their safety. Additionally, if technical challenges arise with a specific intersection, then an alternative one will be selected that has more advanced features.

Appendix A. Acronyms

Table 29 provides a list of acronyms used in this document.

Table 29. List of Acronyms.

Acronym	Definition
ADA	American Disabilities Act
ADS	Automated Driving System
API	Application Programming Interface
ATTRI	Accessible Transportation Technologies Research Initiative
BLE	Bluetooth Low Energy
BNMC	Buffalo Niagara Medical Campus
CO	Contracting Officer
ConOps	Concept of Operations
COR	Contracts Officer Representative
COTS	Commercial of the Shelf
CS	Community Shuttle
CTP	Complete Trip Platform
CV	Connected Vehicle
ET	Enabling Technology
ETRA	Enabling Technology Readiness Assessment
FTA	Federal Transit Administration
GA Tech	Georgia Institute of Technology
GBNRTC	Greater Buffalo-Niagara Regional Transportation Council
GPS	Global Positioning System
GTFS	General Transit Feed Specification
JPO	Joint Program Office
HDS	Human Driven Shuttles
IE	Independent Evaluators
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
ITS4US	Intelligent Transportation Systems for Underserved Communities
LTE	Long Term Evolution
NFC	Near Field Communication
NFTA	Niagara Frontier Transportation Authority
NITTEC	Niagara International Transportation Technology Coalition
NTCIP	National Transportation Communications for ITS Protocols
NY	New York
NYC	New York City
ODD	Operations Design Domain
OSM	Open Street Map
OST	Office of the Secretary
OTP	Open Trip Planner
PAL	Paratransit Access Line
PED-X	Pedestrian Signal Request
PMESP	Performance Measurement and Evaluation Support Plan

Acronym	Definition
PMP	Project Management Plan
PROW	Public Right of Way
QR	Quick Response
REST	Representational state transfer
RSSI	Received Signal Strength Indicator
SDS	Self-Driving Shuttles
SDK	Software Development Library
SOC	Shuttle Operations Center
SyRS	System Requirements Specification
TIH	Transportation Information Hub
TRL	Technology Readiness Levels
UB	University of Buffalo
USDOT	United States Department of Transportation
UW	University of Washington / Seattle
WCAG	Web Content Accessibility Guidelines

Appendix B. Technical References

Table 30 lists the technical references (TR) used to describe the enabling technology and its technical readiness level. The publications are organized in groups that represent the references to specific enabling technologies.

Table 30. Technical References.

TR #	Technical References	Link
TR-1	**Publications related to Smart Phone Positional and Orientation Accuracy**	
	Accessible Transportation Technologies Research Initiative (ATTRI) Performance Metrics and Evaluation, Final Evaluation Framework Report	https://rosap.ntl.bts.gov/view/dot/50748
	Accessible Transportation Technologies Research Initiative (ATTRI) Impact Assessment White Paper	https://rosap.ntl.bts.gov/view/dot/49254
	Smart Wayfinding and Navigation System Using High Accuracy 3D Location Technology, Final Report	https://rosap.ntl.bts.gov/view/dot/44056
	Development of AccessPath: A pedestrian wayfinding tool tailored towards wheelchair users and individuals with visual impairments	https://rosap.ntl.bts.gov/view/dot/55240
	Leveraging Innovative Technology to Develop the Smart Travel Concierge System to Facilitate Pre-Trip Planning and Virtualization for Individuals With Cognitive Disabilities	https://rosap.ntl.bts.gov/view/dot/44053
TR-2	**Publications related to Mobile Apps in PED-X applications**	
	Connecting Pedestrians with Disabilities to Adaptive Signal Control for Safe Intersection Crossing and Enhanced Mobility: 2018 Field Test and Evaluation	https://rosap.ntl.bts.gov/view/dot/39011/dot_39011_DS1.pdf?
	Connecting Pedestrians with Disabilities to Adaptive Signal Control for Safe Intersection Crossing and Enhanced Mobility: Final Report [2019]	https://rosap.ntl.bts.gov/view/dot/50548

	Connecting Pedestrians with Disabilities to Adaptive Signal Control for Safe Intersection Crossing and Enhanced Mobility: 2019 Field Test and Evaluation	https://rosap.ntl.bts.gov/view/dot/43615
TR-3	**Publications related to BLE and NFC "Smart Signs"**	
ACRP	ACRP 177 Enhancing Airport Wayfinding for Aging Travelers and People with Disabilities. (Chapter 8)	http://www.trb.org/Main/Blurbs/176718.aspx
Sun Wei	Sun, D.; Wei, E.; Ma, Z.; Wu, C.; Xu, S. Optimized CNNs to Indoor Localization through BLE Sensors Using Improved PSO. *Sensors* **2021**, *21*, 1995.	https://doi.org/10.3390/s21061995
Porto	Marta Campos Ferreira, Teresa Galvão Dias, João Falcão e Cunha, Is Bluetooth Low Energy feasible for mobile ticketing in urban passenger transport?, Transportation Research Interdisciplinary Perspectives, Volume 5, 2020.	https://doi.org/10.1016/j.trip.2020.100120
Santa Cruz	Mirzaei, F., & Manduchi, R. (2021). In–Vehicle Positioning for Public Transit Using BLE Beacons. UC Santa Cruz.	Retrieved from https://escholarship.org/uc/item/9dv2d7ng
Subryan	Assessment of a Universal Design Smart Sign System. The Journal of Visual Impairment & Blindness. Subryan, H., Khanuja, N. (2021).	TBD
TR-4	**Publications related to Self-Driving Shuttle Technologies and Accessibility**	
Access Board	U.S. Access Board. (July 2021). Inclusive Design of Autonomous Vehicles: A Public Dialogue Summary Report.	https://www.access-board.gov/files/usab-av-forum-summary-report.pdf
	Hyland, M., and Mahmassani, H. (2020). Operational benefits and challenges of shared-ride automated mobility-on-demand services. Transportation Research Part A Policy and Practice 134:251-270.	DOI:10.1016/j.tra.2020.02.017
	Beirigo, B., Schulte, F., Negenborn, R. (2021). Dynamic fleet management for autonomous mobility-on-demand system.	https://www.tudelft.nl/en/3me/about/departments/maritime-and-transport-technology/research/transport-engineering-and-logistics/theme-3-real-time-coordination-for-operational-logistics/dynamic-fleet-management-for-

		autonomous-mobility-on-demand-system
	Ericsson. (2021). Remote Operations of Vehicles with 5G.	https://www.ericsson.com/en/mobility-report/articles/remote-monitoring-and-control-of-vehicles
APTA	APTA. (2019). Public Transit Increases Exposure to Automated Vehicle Technology. *Policy Brief*	https://www.apta.com/research-technical-resources/research-reports/automated-vehicle-technology-exposure/
	Godavarthy, R. (2019). Transit Automation Technologies: A Review of Transit Agency Perspective. Report No SURLC 19-010. North Dakota State University.	https://www.ugpti.org/resources/reports/details.php?id=978
	Cregger, J., Dawes, M., Fischer, S., Lowenthal, C., Machek, E., and Perlman, D. (2018). Low-Speed Automated Shuttles: State of the Practice. Report No. FHWA-JPO-18-692.	https://rosap.ntl.bts.gov/view/dot/37060
	Waymo. (2020). Waymo's Safety Report.	https://waymo.com/safety/
	Y. Shi, A.P. Bartlett, R. Dmowski, D. Duchscherer, Q. He, C. Qiao, and A.W. Sadek. (2021). Safety Evaluation of a Self-Driving, Low-speed Shuttle: Test Scenario Design & Preliminary Data Analysis. *ASCE Journal of Transportation Engineering – Part A Systems,* Vol 147(8).	DOI: 10.1061/JTEPBS.0000535

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