Phase 1 Concept of Operations (ConOps)

Buffalo NY ITS4US Deployment Project

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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 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 describes the Concept of Operations (ConOps) for Phase 1 of the Complete Trip Deployment in Buffalo, NY. This ConOps lists the high-priority user needs, describes the current environment that the system will be developed in, details the high-level functionality and capabilities to be deployed, and defines high-level outcomes and improvements expected from the deployment.

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1. Scope

Buffalo, New York (NY) is one of five sites selected for U.S Department of Transportation (USDOT) Complete Trip - 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 Concept of Operations (ConOps) describes the proposed system as seen and understood by the stakeholders of interest. The ConOps is based on information gathering efforts and stakeholder discussions and is intended to be a non-technical description of the current capabilities, justification for changes and the proposed system that meets the needs of the users.

The ConOps is a foundational document that underpins other systems engineering activities in Phase 1. The ConOps will be a living document until the end of Phase 1 and will be updated as more information becomes available through the planned requirements gathering, partnership and stakeholder engagement activities.

1.1 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 Intelligent Transportation System (ITS) Joint Program Office (JPO) and supported by Office of the Secretary (OST), Federal Highway Administration (FHWA), and Federal Transit Administration (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.

1.2 Acronyms and Glossary

Table 1 lists the acronyms used in the ConOps.

Table 1. Acronyms used in the ConOps.

Acronym	Description
ACS	American Community Survey
ADA	American Disability Act
API	Application Programming Interfaces
AV	Autonomous Vehicle
AWS	Amazon Web Services
BHSC	Buffalo Hearing and Speech Center
BNMC	Buffalo Niagara Medical Campus
BO	Business Operation
BT	Bluetooth
CAV	Connected and Automated Vehicles
ConOps	Concept of Operations
CP	Conventional Pavement
CS	Complete Streets
CTP	Complete Trip Platform
EMC	Emergency Management Center
ETA	Estimated Time of Arrival
EVP	Emergency Vehicle Preemption
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GTFS	General Transit Feed Specification
GPS	Global Positioning System
JPO	Joint Program Office
HDS	Human-Driven Shuttle
HP	Heated Pavement
HTTPS	Hypertext Transfer Protocol Secure
IEEE	Electrical and Electronics Engineers
ITS	Intelligent Transportation System
IVR	Interactive Voice Response

Acronym	Description
KH	Kaleida Health
LEP	Low English Proficiency
MDC	Major Desired Capability
MTOC	Micro Transit Fleet Operations Center
NAV	Navigation
NIDILRR	National Institute on Disability, Independent Living and Rehabilitation Research
NITTEC	Niagara International Transportation Technology Coalition
NFTA	Niagara Frontier Transportation Authority
NSF	National Science Foundation
NTCIP	National Transportation Communications for ITS Protocol
NY	New York
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy and Research Development Authority
OD	Operations and Data
ODD	Operational Design Domain
O&M	Operations and Maintenance
OST	Office of the Secretary
PAL	Paratransit Access Line
PedX	Pedestrian Crossing
PEMP	Performance Measure and Evaluation Plan
PP	Pervious Pavement
PRG	Priority Request Generator
PROW	Public Right of Way
PRS	Priority Request Server
PT	Personalized Trip
PWD	Persons with Disability
ROW	Right of way
RP	Roswell Park
RTK	Real-Time Kinematic
SCP	Signal Control and Prioritization
SDK	Software Development Library
SDS	Self-Driving Shuttle
SOC	Shuttles Operations Center
TDM	Transportation Demand Management
TED	Time of Estimated Departure
TIH	Transportation Information Hub
TMA	Transportation Management Association
TMC	Traffic Management Center
TMDD	Traffic Management Data Dictionary
TNC	Transportation Network Companies
TSD	Time of Service Requested
TTY	Teletypewriter
TWS	Tactile Warning Signals
UB	University at Buffalo
UC	Use Case

Acronym	Description
UI	User Interface
U.S.	United States
USDOT	United States Department of Transportation
V2X	Vehicle to Everything
VIA	Visually Impaired Advancement

1.3 Document Overview

This document is organized following the guidance in *Institute of Electrical and Electronics Engineers (IEEE) 1362-1998 – IEEE Guide for Information Technology – System Definition – Concept of Operations (ConOps)* document.

The primary audience for this ConOps includes the public and private stakeholders that provide and manage transportation services to/from the BNMC and selected neighboring areas. Secondary audiences include the USDOT, which can use this document to develop an evaluation approach of the project.

The remainder of the document is organized as follows:

- Section 2 – References to external documentation used in this document.
- Section 3 – Current system and situation – Summarizes the current mobility and accessibility services, including stakeholders, support environment, modes of operation and any operational policies/constraints.
- Section 4 – Justification for and nature of changes describes deficiencies of the current system/situation specifically as it relates to the needs of its users.
- Section 5 – Concepts for the proposed system describes the proposed system and functionality required to meet the user needs and the changes identified in Section 4. This section describes the key features, the stakeholders and actors, support environment, modes of operation and operational policies/constraints of the proposed system.
- Section 6 – Operational Scenarios include a comprehensive list of scenarios and use-cases to demonstrate how the system works for given contexts and conditions, from the user perspective.
- Section 7 – Summary of Impacts describes the operational impacts of the proposed system on the users, developers, maintenance, and support organizations.
- Section 8 – Analysis of the Proposed System describes the benefits, limitations, advantages, disadvantages, and trade-offs considered for the system.
- Appendix A includes technical information supporting some ongoing research around proposed concepts in the area.

- Appendix B summarizes physical infrastructure improvements planned by the city of Buffalo that will support the Buffalo ITS4US project.

1.4 System Overview

To achieve the ITS4US Complete Trip Program objectives, the project seeks to deploy an integrated suite of technologies chosen to address identified needs of users and gaps within the systems and services provided. The main components of the proposed system are:

- **A Complete Trip Platform Application** (CTP) – an Open Trip Planner based transit trip planning app that is customized for accessible travel. This app will address user needs around improved transit planning and travel support including enroute navigation.
- **Community Shuttle Service** – a shuttle service that is integrated with the CTP and provides circulation in BNMC campus and Fruit Belt area. This service will be based on both human-operated and self-driving shuttles (with an on-board assistant/steward). This component addresses user needs around BNMC local circulation (travel between partner sites and support for first- and last-mile transit connections).
- **Smart Infrastructure** – improvements to digital features in the area of interest (within and around BNMC), particularly along the public rights-of-way. These include adding communication, connectivity and traveler information technologies to the sidewalks and their adjacent loading/parking areas for transportation vehicles, bus shelters, intersections, and wayfinding technologies in indoor and outdoor venues. This component addresses user needs around outdoor and indoor mobility and wayfinding for travelers who have visual impairments or who are deaf or hard of hearing.
- The previous components are monitored through a **Performance Dashboard**, which will be able to ingest log files from the other component and external data sources, as well as store, analyze and provide visualization tools to display and access current and historic data sets produced by the proposed system.

Figure 1 shows the context diagram of the proposed system.

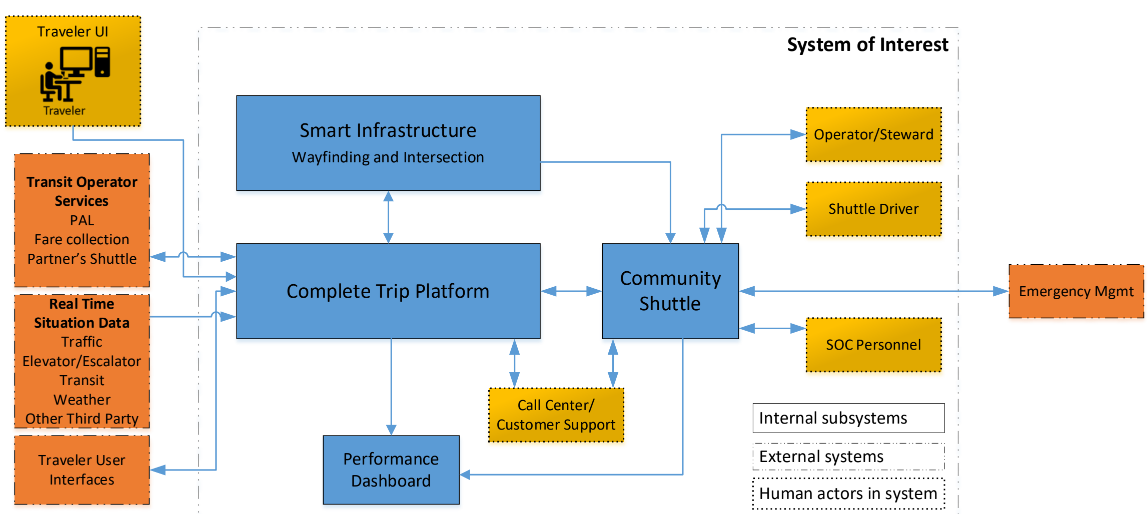

Figure 1. Context Diagram of the Buffalo, NY ITS4US Deployment System.
Source: Buffalo, NY ITS4US

2 Referenced Documents

Table 2 list the documents, sources and tools used to develop the concepts in this document.

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3 Current System and Situation

3.1 Background and Scope

The deployment location is targeted around the downtown Buffalo area with a focus on travel to and from the Buffalo Niagara Medical Campus (BNMC). The deployment includes the 120-acre Medical Campus and surrounding neighborhoods with a focus on three nearby neighborhoods (Fruit Belt, Masten Park, and Allentown) as seen in Figure 2.

The Buffalo Niagara Medical Campus includes nearly 9 million sq. ft. of clinical, research, office and development space. More than 16,000 people work or study at the BNMC and more than 1.5 million visit each year for health care and other services, generating significant transportation demand for the area, its visitors, and its employees. The demographics of the surrounding neighborhoods (see Table 3) are emblematic of a broader socioeconomic and racial divide in Buffalo along Main Street, which this deployment seeks to bridge.

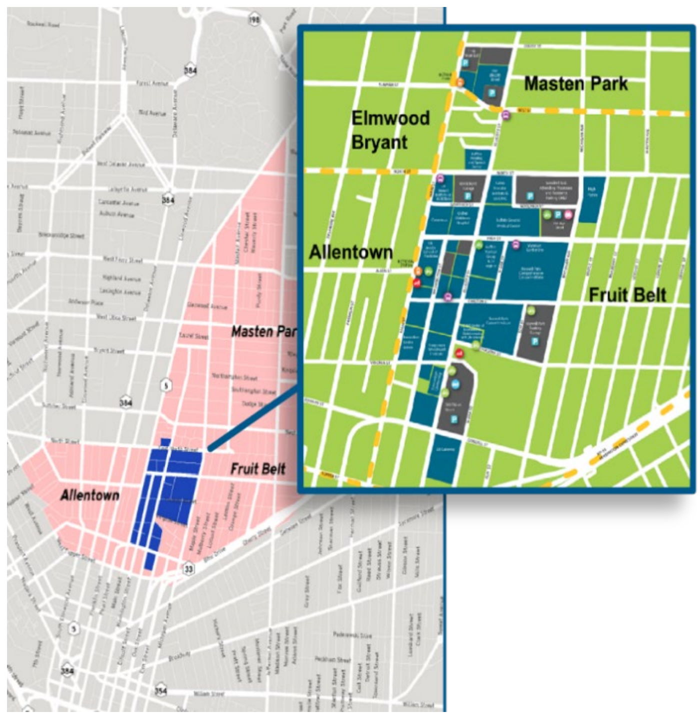


Figure 2. Buffalo Niagara Medical Campus: Allentown, the Fruit Belt, and Masten Park.
Source: University at Buffalo

The BNMC sits adjacent to the Fruit Belt neighborhood, which presents a distinct contrast to Allentown with a poverty rate of 28 and 47% zero-car households. In the Fruit Belt, more than 70% of households are considered "low connectivity households" that either have no internet or depend on one connection type, such as dial-up. Several community and social services are found within the neighborhood, which is relatively close to the wider array of services and jobs offered in downtown Buffalo. Several bus lines serve the area, although headways are relatively infrequent, ranging between ½ hour and one hour. Access to dispersed jobs in the suburbs via public transportation tends to be difficult. Although accessible to the Fruit Belt residents, the Niagara Frontier Transportation Authority (NFTA) Metro Rail station is 0.25 – 0.75 miles away, a distance that becomes amplified during the winter and for travelers with physical difficulties. While BNMC continues to improve pedestrian accessibility, sidewalk quality and intersection crossings still are a challenge for wheelchair users and users with audible or visual impairments. The Fruit Belt struggles with aging infrastructure and infrastructure management issues, issues that have been consistently noted in community forums over the years.

Table 3. Demographics of the targeted neighborhood

Geography (ACS 2018tracts)	Percent 0-vehicle households	Percent population 65+	Percent poverty	Percent Black	Percent Hispanic / Latino	Percent limited English ability	Percent income <$25k	Percent with a disability (18 to 65 yrs. old)	Percent veteran	Percent commute by transit	Total households	Total population
Fruit Belt	**47.0%**	**21.9%**	28.0%	77.0%	8.9%	4.2%	**39.5%**	**20.0%**	**6.7%**	**16.1%**	**976**	**2,435**
Allentown	**18.4%**	6.2%	28.8%	7.2%	6.6%	0.0%	17.4%	8.0%	7.8%	4.8%	1978	3,143
Masten Park	**35.0%**	18.5%	34.7%	89.7%	3.1%	2.9%	38.9%	15.2%	6.6%	11.7%	1496	3,208
Buffalo MSA	**36.6%**	**12.0%**	**31.1%**	**36.6%**	**11.6%**	**4.8%**	**30.7%**	**9.7%**	**5.7%**	**11.5%**	**110701**	**255,423**

Fruit Belt and Masten Park have higher percentages of zero vehicle households, population over the age of 65, with a disability, and incomes of less than $25,000 than the Metropolitan Statistical Area (MSA) averages. The Allentown neighborhood is not characterized by underserved populations, it contains a high concentration of transit service and commercial activity, including health care offices. Allentown hosts several significant bus lines (including the #20-Elmwood, the #25-Delaware, the #11-Colvin, and the #8-Main) that connect the BNMC and Downtown Buffalo with neighborhoods to the north, carrying over 10,500 riders on an average weekday.

As per the bi-annual commuter survey performed by the BNMC in 2020, around 58% of the employees drove alone all the time, followed by nearly 10% of the employees who drove most of the time. These number are very similar to pre-COVID conditions were nearly 63% and 10% of employees drove to work alone always and most of the time, respectively. Pre-COVID, around 4% and 2% took the rail and bus to work, respectively. As expected, the biggest change has been in the percentage of people that now work from home at least most of the time, increasing from nearly 4% to 24%.

3.2 Description of the Current System and Situation

The current system is composed by a set of mostly disjointed services, infrastructure and tools—as seen in Figure 3. Transportation options within the BNMC study area include driving, public transit, walking and biking to campus. There are complementing research and planned improvements within the area of interest that could be leveraged, which are discussed later in this subsection.

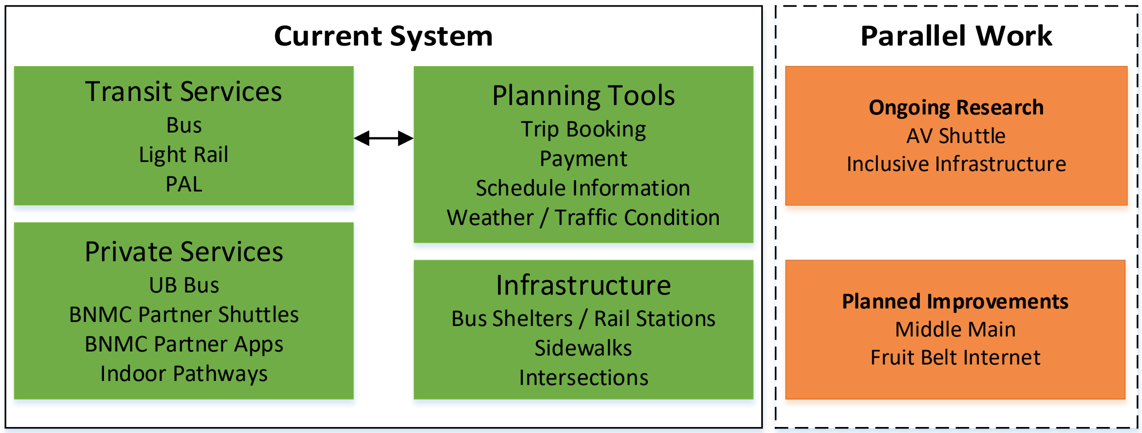


Figure 3. High level concept diagram of the current system.
Source: Buffalo, NY ITS4US

At a summary level, travelers using the current system have the following experiences:

1. Travelers with disabilities who are eligible for NFTA's paratransit access line (PAL) have the ability to get shared door-to-door service through the PAL Direct system. Travelers have to book an eligible trip a day in advance through the system. Trips are from door-to-door, so the traveler is on their own once at their destination door.

2. Travelers with disabilities can also travel on fixed route services (like the NFTA Metro bus and rail) and if they are PAL-eligible, travel for free on the fixed route service. Metro buses are all equipped with wheelchair lifts and ramps, announce major stops, and allow service dogs and personal care attendants. Similarly, all Metro Rail trains and stations are accessible to riders with disabilities. Passenger assistance communication equipment (PACE) is available at each Metro Rail station. This equipment may be used to obtain information or to report an emergency. In the event of an elevator breakdown, wheelchair users may use the PACE panel to request assistance. Riders will be advised to travel to the next station with a working elevator and take the next scheduled bus back to the station you called from, or a replacement bus or lift equipped Metro supervisor van will be dispatched to pick them up.

3. Older or low-income travelers are eligible for a reduced fare on NFTA services through a reduced fare pass program.

4. All travelers have a variety of applications and information services to help inform them about transit and travel conditions. These are described later in this section, but no single app supports a complete trip from a traveler's perspective.

5. For all fixed route services, travelers have to navigate to their destination from the fixed route bus stops and rail stations using the existing physical infrastructure that is of varying quality and not continuous in its ability to support accessible travel.

6. While new services like transportation network companies are present in Buffalo, travelers with disabilities find it hard to get accessible vehicles for their travel needs leading to a high dependence on either private auto or on public transit.

7. Various other travel options are available based on eligibility. For example, BNMC entities run several shuttles that support their own employer and visitor travel needs. In many cases, a traveler would need to show that they are eligible to use the service. Not all of these shuttles are fully accessible.

8. Finally, between select buildings in the BNMC, travelers can use the covered bridges or pathways to travel without coming back out to the street. This is particularly useful during winter months. However, the pathways are not fully connected to all the buildings and nor are they completely accessible to all travelers. Some sections may be access-restricted based on the partner's security policies.

As is clear from the travel experience, there isn't a current method or service that would allow travelers to plan, execute a complete trip especially if they have mobility-related needs. Rather, a traveler would have to negotiate a number of applications, services, infrastructure elements and policies to successfully complete a trip.

Building from these traveler experiences, the following subsections describe the condition of infrastructure, assets and services that impact a traveler's trip and the different systems and services currently available to plan and execute their trips.

3.2.1 Existing Infrastructure, Assets and Services

This subsection describes the different infrastructures and the information that is available to users while planning and traversing to/from/within the BNMC campus. These include streets, sidewalks, bus shelters, intersections and other transit infrastructure with which travelers interact with during their trips.

3.2.1.1 Streets and Sidewalks

The city of Buffalo contains around 2,000 miles of sidewalk (WKBW, 2021). However, their condition and accessibility vary by location and season. In the project area, the Fruit Belt neighborhood struggles with aging infrastructure and management issues, topics that have been consistently noted in community forums over the years (Sasaki & Madden Planning Group, 2009). Key issues include:

- General sidewalk conditions including lack of sidewalk curbs, narrow and undefined sidewalks and sidewalk repairs.
- Deficiency of crosswalks.
- Untended street repairs.
- Lack of street tree maintenance and management.
- Proliferation of exposed utility poles and wires.
- Lack of building maintenance.
- Absence of signage and design standards.

Weather events (e.g., rain and snow) intensify these issues with streets and sidewalks, with sometimes serious impact on pedestrians, especially those who have disabilities.

3.2.1.2 Bus Shelters

The Buffalo metro area currently has over 4,500 bus stops but only 250 shelters—so roughly five percent of boarding locations possess shelters (NFTA, 2019). The current NFTA bus shelter presents a number of issues that might challenge, inhibit or discourage new and experienced users—see Figure 4. Common issues include:

Figure 4. Bus Shelter on Buffalo.
Source: University at Buffalo via Easter Seals Project ACTION (2014)

- Lack of information:
  - No schedule information.
  - No real time information on wait time or bus location.
  - No individual or regional bus route map(s).
  - No “station name” sign.
  - Customer service number confusing for first time passengers.
- Lack of direct lighting, which can influence traveler’s perception of safety.
- Lack of seating to meet demand of transit passengers at certain stops.
- Lack of universal bus sign, with no bus logo or pictogram indicating that the shelter is for a bus.
- Small shelter width, with slightly above four feet wide (49 inches).
- During winter, shelters may not always have a clear and accessible path to them.

3.2.1.3 Intersections

There are more than 600 intersections city wide, mostly maintained by city of Buffalo. Intersections are not centrally controlled or coordinated. There are 33 intersections surrounding BNMC, all owned by the city of Buffalo except for one (Main & Goodell), which is owned by New York State Department of Transportation (NYSDOT). Two intersections are particularly critical to the overall connectivity of the campus to the community and access to the transit services (Main/Best and Ellicott/High).

The Main/Best intersection is currently part of the Middle Main Street project (see Section 3.2.1.6) that includes physical infrastructure investments in this intersection, as well as the BNMC Smart Corridor project. It is a multimodal (rail/bus/pedestrian) site which introduces more complexity than other intersections. There are two BNMC partners located near this intersection, Visually Impaired Advancement (VIA), which serves a visually impaired population, and Buffalo Hearing and Speech, which serves a population with hearing, speech and cognitive impairments.

The Ellicott/High intersection is an active pedestrian corridor and is a key node on the BNMC with close to 2000 pedestrians using the intersection daily. There are specific safety concerns due to the hilly topography (for Buffalo) and it serves key target populations, including visitors to two major hospitals and their employees.

There are no connected technologies nor preemption/priority devices equipped in the intersections near BNMC, as can be seen in Figure 5. Inductive loop detector (for actuated signal control) is the only technology; however, the Middle Main Street Project, operated by the city of Buffalo, is considering installing conduits at designated intersections for future use.

Figure 5. Intersection of Main St and High St.
Source: Google Maps

Currently, intersections are not centrally controlled and there is no communication back-haul in place.

In terms of notifications, very few intersections provide information to pedestrians regarding the time to cross (particularly to those who have a disability). The only information available is auditory notifications (through a "beep") when the crossing button is pressed. In addition, there are some Wi-Fi access points along certain section of Main Street whose main function is to provide Internet access. However, these are not adequate, in terms of both bandwidth and coverage, to support the communication needs of smart intersections for pedestrians and advanced shuttle services.

3.2.1.4 Transit Service

NFTA-Metro is the public transportation agency for Erie and Niagara Counties of Western New York. Metro covered 11 million miles in 2019 and serves nearly 24 million people each year. Figure 6 provides an overview of the assets and performance of NFTA's transit services, described in more detail below (NFTA, 2020):

- Bus – during 2019, the bus services had a ridership of around 19.4 million riders, a slight increase from the year before. The bus service counts with 59 routes, around 4,500 stops and a fleet of 321 buses. Bus service has an average 85% on time performance.

- Rail – during 2019, the rail service had a ridership of around 4.2 million riders, a roughly 6% decrease from the previous year. The service counts with 27 cars, with an average age of around 7.6 years, to traverse through its 6.4 miles of rail. There are 43

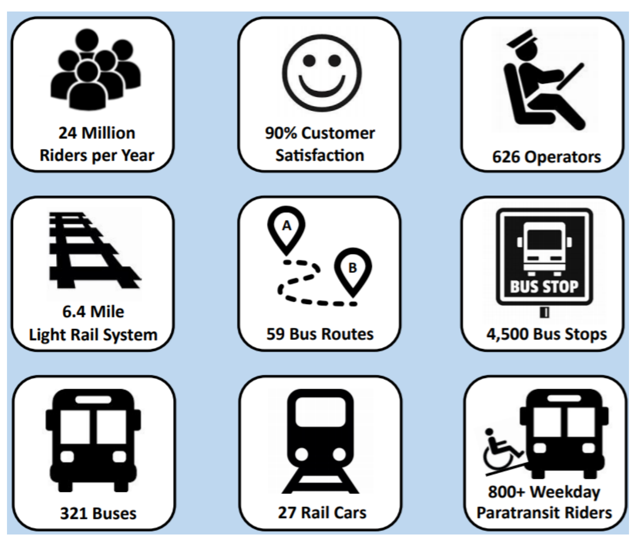


Figure 6. Overview of NFTA's transit services.
Source: NFTA (2020)

elevators distributed across the rail stations, with their status being constantly monitored and shared with the public through NFTA's website.

- Paratransit – while the bus and rail systems are accessible, Metro provides the Paratransit Access Line (PAL) for passengers who cannot access the Metro Bus and Rail due to a disability (temporary or permanent). PAL operates during the same days and times that the regular bus and rail system is available in an area, Reservation are available 7 days a week, from 8:00 AM to 4:00 PM, and can be made up to 14 days in advance, but no less than 4:00 PM the day prior. Paratransit service counts with almost 100 dedicated operators and 75 vehicles. Metro allows PAL eligible riders to use fixed route service free of charge in an effort to minimize demand for PAL service. A person is eligible for PAL if, because of their disability, they (NFTA, 2021):
    - Cannot independently board, ride or exit from any vehicle on the fixed route bus or rail system which is accessible and usable by individuals with disabilities.
    - Cannot use an accessible fixed route vehicle, but the route or the accessible vehicle on the route that would be used is not accessible or usable, or the stop that would be used is not accessible or usable due to the physical characteristics of the stop.
    - Cannot independently travel to or from the fixed route bus stop or rail station.

As for payment of transit services, cash only ticket vending machines (GFI® Fareboxes) are located in all Metro Rail stations, Metropolitan Transportation Center, Portage Road Transportation Center and Niagara Falls Transportation Center. These machines accept U.S. coins, $1, $5, $10 and $20 bills. There is also a smartphone application for payment, Token, discussed in Section 3.2.2.

Currently the BNMC area is served by the following NFTA bus routes, light rail, paratransit and other transportation options (as seen in Figure 7):

- Fixed route bus:
    - North/South routes: #8-Main, #11-Colvin, #14-Abbott, #16-South Park, #18-Jefferson #20-Elmwood, #25-Delaware
    - East/west routes: #12-Utica, #13-Kensington, #22-Porter-Best
- Light Rail: Allen/Medical Campus Station and Summer-Best Station connect to the NFTA Metro Rail system (one line connecting Downtown Buffalo with the University at Buffalo South Campus).
- Paratransit: Paratransit Access Line (PAL) service is provided to qualified individuals within 3/4 of a mile of an NFTA-Metro bus route or rail station during the same hours and on the same days as the NFTA-Metro fixed route service.
- Bikeshare: Two Reddy Bikeshare stations are located on the medical campus, linking to an affordable, citywide network of dozens of hubs and hundreds of bikes.

- UB safety shuttle: an on-demand service that operates at night, 8pm to 4am.

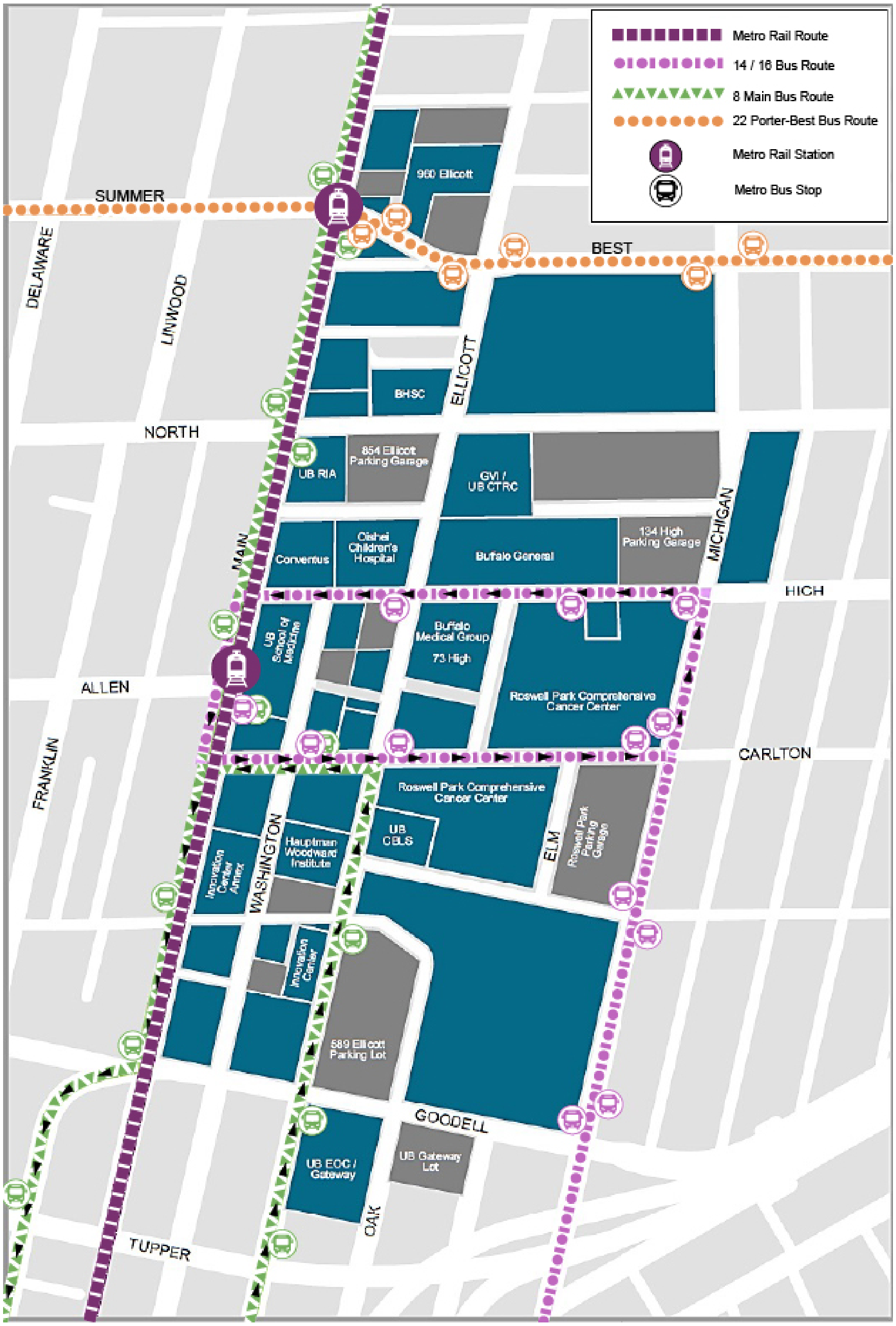


Figure 7. Public Transportation in the BNMC Area.
Source: BNMC. (Edits are made for Section 508 Compliance)

3.2.1.5 *Partner Services and Infrastructure*

Within the BNMC, many health care partners provide several services and access to infrastructure to optimize travel within and between buildings and other infrastructures (e.g., parking). The following are such services and infrastructures:

- MyKaleida Mobile App – the health service provider Kaleida Health has a mobile application that provides indoor directions from all locations within their buildings and between buildings (see Figure 8). However, this is not a dynamic application and does not track your location, nor provide real time notifications on when/where to make turns.

Figure 8. Screenshot of MyKaleida mobile app.
Source: Kaleida Health (2021)

- Public Safety Escort Shuttles – major institutions provide public safety escorts via a shuttle on an on-demand basis. For instance, the University at Buffalo (UB) has a "safety shuttle" available to students, faculty and staff needing a ride within a 1.5-mile radius of the UB South Campus. Operating as an on-demand service (requested via smartphone app), weekdays from 8:00 PM to 1:00 AM during the fall and spring semesters. Another example is Roswell Park, which offers a free shuttle that will take anyone visiting their infrastructure to/from their vehicles to/from a Roswell Park building, as long as they are within a 0.5 mile of the building.

- Circulator and Other Mobility Shuttles – UB also has a fixed route Blue Line Shuttle, which connects South Campus and BNMC and has six stations in BNMC. The city of Buffalo and Erie County both have vehicles (vans) that are used specifically to provide mobility services to people with disabilities—for these, reservations need to be made two weeks prior to the trip.

- Call Center - VIA operates a call center that provides travel guidance and information to callers.

3.2.1.6 *Planned Infrastructure Improvements*

The following are planned improvements (outside of this project) that could support the ITS4US Deployment.

Middle Main Street Corridor Improvements

The city of Buffalo has secured over $18 million to improve the street infrastructure of Middle Main Street (between Goodell Street and Humboldt Parkway), including a full-street reconstruction between Goodell and Ferry, and mill and overlay between Ferry and Humboldt, until more funding is identified to continue full reconstruction to Humboldt. The city of Buffalo is planning Phase I of the Middle Main Street Streetscape Project, which will rehabilitate the streetscape in order to provide a safe and convenient environment for walking, driving, and biking while increasing community connectivity and helping to improve overall quality of life.

The first phase of the project will provide improvements from Goodell Street to Ferry Street, as shown in Figure 9. The city of Buffalo conducted community outreach from Fall 2019 through Summer 2020 to develop alternative design proposals through 2021. The typical existing cross-section of this corridor features 99-foot-wide public-right-of way with four travel lanes (two in each direction) and two parking lanes (one in each direction).

In Summer 2020, the city of Buffalo presented a proposed design that improves space and amenities for pedestrians and bicyclists. Vehicular travel lanes are reduced to three (one travel lane in each direction and a center two-way left-turn lane), the addition of a sidewalk curb extension with parking, and a two-way protected cycle track.

Figure 9. Middle Main Street Streetscape Project Phase I.
Source: City of Buffalo (2020). (Edits are made for Section 508 Compliance)

The project is currently in conceptual design phase and will be ready for construction in mid-2022.

High-Speed Internet Access in Buffalo's Fruit Belt

The University at Buffalo (UB) and the local nonprofit Mission: Ignite were awarded $300,000 in federal funding to expand high-speed internet access in Buffalo's Fruit Belt neighborhood, providing internet service at no cost to 150 households (Nealon, 2021). UB and Mission: Ignite lead the project team, which includes partners from the region such as The Community Tech New York, The John R. Oishei Foundation, Kaleida Health, Integrated Systems, city of Buffalo, and New York State Wireless Association. The award is part of Project OVERCOME, a $2.7 million initiative run by U.S. Ignite, funded by the National Science Foundation (NSF) and Schmidt Futures, a charitable organization, aiming to expand high-speed internet access to underserved communities.

The project will use part of the wireless spectrum known as Citizens Broadband Radio Service. Mission: Ignite will be the operational owner of the network and will train local digital stewards to provide ongoing maintenance and community support. The expectation is that reliable high-speed internet will help mitigate educational gaps in the Fruit Belt and improve access to telemedicine. Additionally, by training stewards to maintain the system, the project will help give people job skills. The project expects to be deployed by end of 2021 and it would be free to the community.

Touch Model Installations for BNMC

Travelers need to be oriented as they enter specific buildings within BNMC (e.g., Oishei Children's Hospital, Buffalo General Hospital). A Touch Model is being deployed to provide enhanced information than typically found on "You are Here" maps—see Figure 10. A Touch Model combines a touch sensitive display and transparent overlays with raised lines, textures and three-dimensional scale models. Individuals can touch any part of the model to activate voice, graphic output illuminated through the overlay, or even refreshable Braille.

Touch input is superior to text and audio in public places because it provides a more immersive experience, does not require high levels of dexterity and accuracy, eliminates interference from background noise, and is more intuitive than text or voice input. Multiple output modes increase comprehension and accommodate limitations in sensory abilities. The displays provide customized views of a site or building (e.g., aerial photograph of a campus and diagrammatic plan of a building). The IDEA Center currently has a grant to build a Touch Model for the Innovation Center, the headquarters of the BNMC and home to their business incubator.

Figure 10. Interactive Touch Model.
Source: Photo courtesy of Steve Landau, Touch Graphics Inc.

3.2.2 Trip Planning and Execution Tools

This section provides details on the tools available to travelers to plan and execute their trips. Table 4 provides a list of tools that are available in the area for travelers and their capabilities.

Table 4. Trip Planning and Execution Tools in the Buffalo Area.

Tool	Description	Capability(ies)	Limitations
Trip Planner	NFTA managed webpage (http://infoweb.nfta.com/) that provides traffic information to help users plan their trips. The application allows users to get directions by choosing an address or intersection or landmarks as start or end point, it allows users to plan the trip on real-time or scheduled time in the future. It also provides options for accessible trips.	Trip Planning (static)	Start and end the trip at bus or metro stops, no guidance on the walking part (last mile problem).
PAL Direct	NFTA's 24 hour automated online trip scheduling system (https://paldirect.nfta.com/). From this site, users can schedule, cancel and review their	Trip Planning (reservations)	Cannot accommodate same-day requests. Limited only to

Tool	Description	Capability(ies)	Limitations
	trips, submit feedback and review their PAL customer information.		PAL eligible travelers
Where's My Bus	NFTA's managed webpage (http://wmb.nfta.com) that provide real-time buses and rail information to help users plan their trips ahead. The application allows users to get estimated time of arrival by route or stop.	Trip Planning (real time)	No access to exact bus location. Rough estimation based on schedules.
Smart Traveler	NFTA managed webpage (http://smarttraveler.nfta.com/) that provide buses schedule information. It allows users to search planned schedule of all the bus lines by stop, route and address.	Trip Planning (static)	Hard to find information unless users are familiar with the stops and routes.
Elevator / Escalator Status Checker	NFTA managed webpage (https://metro.nfta.com/special-services/elevator-escalator-status) that provide real-time Metro Elevator and Escalator status information.	Trip Planning (status)	Status inputted manually; delays could occur. Alternatives are available only as pdf maps
Maps and Schedules	NFTA managed webpage (https://metro.nfta.com/schedules/routes) that provide map and bus schedules in the area.	Trip Planning (static)	Large scale complicated map that is hard to read
511NY	NYDOT developed telephone and Web service (https://511ny.org) which offering information on transportation services and conditions throughout New York State. It provides trip planning resources, traffic conditions, weather updates and alternative transportation information which meet the specialized need of commuters, long-distance and through travelers, tourists and commercial vehicle operators.	Trip Planning (static and real time)	Only contains event information on major arterials and highways.
Moovit	NFTA managed mobile App and website (https://moovitapp.com/buffalo_ny-1402/poi/en?customerId=11514) that provide real-time buses and rail information to help users plan their trips. The application allows users to	Trip Planning (third party)	No enroute trip guidance.

Tool	Description	Capability(ies)	Limitations
	get directions by choosing starting point and destinations, it also provides bus lines information and real-time status.		
Google Maps	This desktop and mobile platform allow users to assess available mode choice alternatives.	Trip Planning (third party)	Limited to people with access to internet and smart phones.
Transit	Third party App run by Transit (https://transitapp.com/) which provides traffic information and navigation services. It provides information of all modes of transportation tools. It allows users to plan the trips and get instructions during the trips.	Trip Planning and Execution (third party)	No payment integration in the area. Not connected to PAL.
Token	A smartphone application that allows users to pay for NFTA Metro bus or rail fares. On the Token Transit app, users can purchase the following tickets for immediate or future trips: • Single ride (bus/rail) • Round trip rail • Day pass • 7 Day pass • 30 Day Pass • Paratransit Single Ride, 10 and 20 pass packages • Enhanced Express bus	Trip Payment (third party)	Limited to people with access to internet and smart phones.
NITTEC	NITTEC hosts a Mobile App that provides traffic and roadway information to improve traffic flows and enhance emergency assistance for motorists. The application allows users to access traffic maps, camera images, travel advisories, border-crossing times, and construction alerts.	Trip Planning (road conditions)	Limited coverage on local roads.

For the most part, these tools operate as isolated information sources and functionality for travelers. None of the tools support end-to-end, complete trip, hands-free trip planning and journey support. Travelers need to consult more than one of them to plan a trip. Existing data source standards or specifications that feed these applications include the following:

- NFTA General Transit Feed Specification (GTFS) and GTFS real time (GTFS-r) on their bus and rail systems

- ITE Traffic Management Data Dictionary v. 3 (using the Transcom profile SPATEL (Selected Priorities Applied to Evaluated Links) data feed.

3.2.3 UB Campus Self-Driving Shuttle Demonstration

In 2018, the University at Buffalo (UB) was granted funding from the New York State Energy and Research Development Authority (NYSERDA) and from New York State Department of Transportation (NYSDOT), to conduct a preliminary evaluation of the technical feasibility, safety, and reliability of using AV technology, and specifically a self-driving, low-speed shuttle called Olli (Figure 11) to provide for a self-driving shuttle (SDS) capable of transporting passengers safely and reliably. The study also gauged public acceptance of AV technology and Olli and conducted a simulation-based study of a detailed evaluation of the costs and benefits of using AV technology on a realistic case study involving the BNMC in downtown Buffalo.

The BNMC was used as a case study to assess the feasibility of Olli to provide “last mile” service from a financial standpoint. Evaluating the feasibility, costs, and benefits of Olli for BNMC encompassed the following sub-tasks:

Figure 11. The Self Driving Shuttle Olli being tested on UB Campus.
Source: University at Buffalo

- Assess the mobility needs and service objectives of the medical complex in close collaboration with its principal stakeholders.
- Design the network and routes for Olli to effectively serve BNMC.
- Design the mode of operations for the Olli bus and determine vehicle frequency.
- Derive performance measures from model results and estimate cost and benefits of operations.

Figure 12 shows the simulated circular route for serving the BNMC with SDS. The figure also shows the locations of six suggested SDS stations (S1 through S6) where users would board or get off the SDS. The study also conducted a simulation study and a business case analysis of the scenario in Figure 12. The case study analyzed the financial viability of Olli deployment under three possible approaches: (1) a public plan, (2) a private plan, and (3) a public-private partnership. For a public plan, the total annual cost would be around $1,365,000/year, which would be borne by BNMC or some other public entity. Under a private plan and based on a ridership of 270,000 trips per year the break-even cost per rider would be $5.05/trip or with a modest profit, $5.50/trip. Finally, for a public-private partnership, whereby the public entity is responsible for the capital cost and the private entity is responsible for the operating costs, the cost per trip would be approximately $1.75 (Sadek, et al., 2021). Findings related to safety, security, public acceptance of SDS are provided in Appendix A.

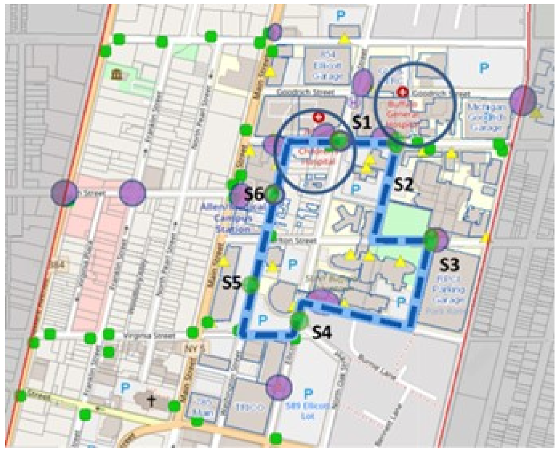


Figure 12. Simulated Olli Route for Serving BNMC.
Source: Sadek, et al. (2021) *(Modified for Section 508 Compliance)*

3.2.4 Regional Mobility Programs and Services

Regional mobility programs and services provide employers, commuters, and other travelers with transportation demand management (TDM), traveler information, outreach and education, and mobility options. Specific programs and services include 511NY Rideshare, the regional Go Buffalo Niagara transportation management association (TMA), the GO BNMC TMA, GObike Buffalo, and Reddy Bikeshare.

- The 511NY Rideshare program (https://511nyrideshare.org/) is sponsored by the NYSDOT and serves travelers throughout New York State by providing transportation information, tools, and services to support and encourage the use of sustainable transportation. 511NY Rideshare provides the technology for locally branded rideshare portals that are account-based, enabling travelers to set their travel preferences to find carpool partners, bike friends, transit routes, park & ride lots, and real-time traffic conditions. In the Buffalo-Niagara region, 511NY Rideshare provides locally branded rideshare portals for the Go Buffalo Niagara TMA, the GO BNMC TMA, University at Buffalo, Erie County, and other organizations. In addition to the traveler information and matching technology provided in rideshare portals, the 511NY Rideshare program offers customer support, seasonal campaigns, and print and digital marketing collateral to promote sustainable transportation options.

- The Go Buffalo Niagara TMA is a one-stop source of information on transportation options for employers and commuters in Erie and Niagara counties. Go Buffalo Niagara is managed by GObike Buffalo and is a close partner of the GBNRTC, the NFTA, the BNMC, and others. Go Buffalo Niagara provides the following services to the region:

    - Provides a unified regional direction for TDM goals and objectives
    - Coordinates regional branding and marketing of TDM services
    - Delivers TDM services regionally, including technical assistance to employers and developers, and personalized assistance to travelers

  - Identifies local TDM needs and supports local TMAs (including GO BNMC)
  - Serves as a vehicle for regional TDM financing
  - Spearheads regional transportation advocacy
  - Administers TDM monitoring and evaluation
  - Administers regional and local 511NY Rideshare portals in partnership with NYSDOT

- The GOBNMC TMA (https://bnmc.org/go-bnmc/ways-to-get-here/) is a campus-wide initiative to create a more sustainable and active transportation system for employees on the Buffalo Niagara Medical Campus. It has fostered a strong foundation of multi-modal transportation options at the medical campus since 2012, with over 900 campus employees registered for benefits such as guaranteed ride home or preferred carpool parking. GOBNMC has engaged across the institutions on the medical campus to reduce the drive alone commute rate from 88% in 2012 to 80% in 2018, which equates to reduced parking demand by over 1,200 spaces. GO BNMC offers a variety of transportation benefits to employees and students on the medical campus who commute by alternatives to driving alone. Benefits include guaranteed ride home in case of an emergency, carpool parking permits, two free parking validations per month on days that commuters have to drive alone, monthly raffles, free transit trials to parking permit holders, free membership to Reddy Bikeshare, and secure bicycle parking.

- GObike Buffalo (https://gobikebuffalo.org/) manages the Go Buffalo Niagara TMA as well as secure bicycle parking at the BNMC. GObike operates a community workshop located in North Buffalo; the workshop is a space for people of all ages and abilities to learn bike repair skills and purchase low-cost refurbished bicycles. Additionally, GObike offers a membership program providing individuals with unlimited access to their community workshop; discounts to GObike events, including group bicycle rides and education classes, and more.

- Reddy Bikeshare (https://reddybikeshare.socialbicycles.com/) operates 400 global positioning system (GPS)-enabled bikes at 90 different stations throughout the cities of Buffalo and Niagara Falls between April and November. Within the BNMC, there are three Reddy Bikeshare stations (one at the Summer-Best Metro Station, one at the Allen Street Metro Station, and one at the intersection of Virginia and Ellicott Streets). The GOBNMC TMA offers free annual Reddy Bikeshare memberships, a $55 value, to all students and employees at the BNMC.

3.3 Current System Stakeholders

There are two main stakeholders of the current system: Travelers who use the system and Operators/Partners who provide and manage the infrastructure and services. Table 5 describes the traveler and the different characteristics. This table describes the end-users of the services, infrastructure and assets who ultimately make the trips in and around the campus.

Table 5. Current Stakeholders included in the Traveler Group

Actor	Short Description	Roles and Responsibilities
Traveler	The traveler actor describes the people living in the Buffalo region, and especially in the neighborhoods surrounding the BNMC who need to live, work and travel in the area. In particular, the traveler actor includes the following groups: **Persons with Disability (PWD)** A person with a disability is defined by the American Disability Act (ADA) as a person who has a physical or mental impairment that substantially limits one or more major life activities, a person who has a history or record of such an impairment, or a person who is perceived by others as having such an impairment[1]. For the purpose of this deployment, users with five types of disabilities are identified: • Mobility – Travelers with various physical disabilities that affect both gross and fine motor skills that may require a personal assistance device. • Vision – Travelers who are blind or have low vision. • Cognitive – Travelers with cognitive disabilities. • Hearing – Travelers who are completely or partially deaf. **Low Income** Travelers with annual incomes <26K that use and travel in the area. **Older Adults** Travelers who are over the age of 70. **Low English Proficiency (LEP)** Travelers to BNMC who do not use English as their primary language of communications.	Rely on the existing infrastructure, services, tools and programs to meet their travel-related needs

Table 6 provides the list of operator/partner actors, as well as their roles/responsibilities. These actors provide and operate the services, infrastructure and tools necessary to support the traveler's needs.

[1] Source: https://www.ada.gov/cguide.htm#anchor62335

Table 6. Current Operator/Partner Actors.

Actor	Short Description	Role / Responsibility
NFTA Paratransit Operations (PAL)	Systems (call center, web, and phone) and personnel used to support PAL operations.	Operate the paratransit service in the region including trip reservations, dispatch and transit service delivery.
NFTA Operations	Systems and personnel involved in NFTA bus and rail operations. Also includes public and private traveler information systems currently in use at NFTA (Transit, Moovit, Agency website, phone) and associated personnel.	Operate the bus, rail services in the region. Provide traveler information tools and services.
City of Buffalo Operations	Systems and personnel responsible for the streets, signals, sidewalks, bridges, traffic systems in the deployment area.	Operate the City signals and public works.
NITTEC	Systems and personnel responsible for traffic operations collaboration in the Buffalo region.	Provide regional operations coordination between transportation agencies in the Buffalo area by exchanging data, information and coordinating response to events.
Regional Travel Demand Management (TDM) Services	Systems and personnel involved in travel demand management activities in the region including campus-wide initiative to create a more sustainable and active transportation system for employees on the Buffalo Niagara Medical Campus (BNMC TMA), statewide mobility management services (NSYDOT 511NY Rideshare).	Provide travel and mobility management services, employer outreach, travel demand management.
NYS Department of Motor Vehicles	Systems and personnel responsible for permitting self-driving shuttle operations.	Provide oversight of vehicle operations in New York State.
Emergency and Law Enforcement Entities	City, state and transit law enforcement and emergency systems and personnel responsible for monitoring emergency, safety of traffic and transit operations. Includes City of Buffalo, NFTA and NY State Police that may have jurisdiction in the system of interest.	Provide local law enforcement activities and emergency management support.
BNMC Inc.	Systems and personnel involved in the non-profit organization that facilitates collaboration and address shared issues among member institutions that form the 120-acre Medical Campus and our surrounding neighborhoods.	Manages parking as well overall transportation planning collaboration for the BNMC campus. Also runs the TMA
BNMC Campus Entities	Partners included in the BNMC Transportation Management Association. Input from representatives from each of the partner agencies on travel needs for their employees and visitors. User group includes systems and personnel involved in partner's specific parking, access and traveler services. Five sub-groups are identified here around each for the partner agencies: • Roswell Park (RP)	In addition to their core healthcare mission, transportation roles of the campus entities are to provide travel support to their employees and visitors including travel planning, parking and local circulation.

Actor	Short Description	Role / Responsibility
	• Visually Impaired Advancement (VIA) • Kaleida Health (KH) • University at Buffalo (UB) • Buffalo Hearing and Speech Center (BHSC).	

3.4 Support Environment

Current support systems and tools are extensive in the region as discussed in Section 3.2 above. Other elements include:

- **Data collection, processing and distribution** including NITTEC traffic information, NYSDOT GTFS Data Manager, NFTA real time data feeds and other situational awareness sensors.

- **Research labs** testing accessibility equipment and methods through the IDEA Center and UB's Proving Grounds for Connected and Automated Vehicles (CAV). Information on the current research and facilities are described in Appendix A.

- Middle Main Street construction is developing templates for **"Complete Streets"** models for the region including better pedestrian accessibility at crosswalk, sidewalks, multimodal transport (bike lanes and parking), and pickup locations.

- As noted earlier, no communication infrastructure is available to the intersections. However, an ongoing grant to support **expansion of high-speed Wi-Fi** internet in the Fruit Belt neighborhood might provide some communication capabilities that can support the project area.

- **Existing and planned infrastructure** at bus stops, rail stations, and BNMC buildings. This also includes **maintenance plans** from the infrastructure and service owners/providers.

- **Parking garages and facilities operated by BNMC Inc** and partner agencies around the campus. These garages can often be the starting or ending point for pedestrian travel to and from the campus.

- **Covered indoor pathways** – many of the BNMC buildings have internal pathways that connect them, allowing for more direct trips, but also ensuring safe and accessible mobility during winter and severe weather. Within the BNMC campus, nurses, doctors and researchers can travel nearly 0.75 miles through nine connectors bridging key medical facilities, hospitals and research centers (Robinson, 2017). It is important to note that not all pathways are available to the public or may have restrictions (such as hours of operations and security restrictions).

- City of Buffalo continues to i**mprove their sidewalks per sidewalk master plan**.

- **Bus shelter expansion program.** NFTA Metro has an ongoing plan to add up to 40 additional shelters annually over the period 2020-2023 in order to provide better customer facilities and align more closely with peer agencies. However, these new shelters will not necessarily address all the issues listed above, particularly those that relate to providing real time information. NFTA Metro has taken steps to obtain real-time signage, but currently only provide real-time signage at three transit centers and one rail station.

- Infrastructure maintenance activities are shared between NFTA, City of Buffalo, BNMC, Partner agencies and businesses especially around snow and ice clearance around sidewalks and transit facilities (conducted by NFTA).

3.5 Modes of Operation for Current System

Each of the systems and services, currently deployed operates as closed, independent systems, and thus, will not be significantly affected by the modes of operations of the "current system" as a whole. The modes of operation for the systems including transit (rail, bus and PAL) and traffic signal operations each have separate modes of operations that change based on criticality of the service they provide, as detailed in Table 7 and Table 8.

Table 7. Modes of Operation for Current Transit Planning Services.

Mode	Definition
Operational (regular)	All services operate with all static GTFS and real time / status information coming from on-board or track sensor systems.
Degraded	There are multiple channels to access transit information. When one fails or is degraded then customers can access alternative tools. However, these are data driven services ingesting transit and roadway real time and situational information. When those systems degrade or fail, up-to-date information lags. Some tools will include a banner that identifies that there is a problem with the real-time data feeds.
Failure	Failure mode reverts to provide static / scheduled information to the customer. Some tools will include a banner that identifies that there is a problem with the real-time data feeds.

Table 8. Modes of Operations for Transit Operations (Light rail, bus and PAL).

Mode	Definition
Operational (regular)	The **rail system**, as a critical infrastructure component, includes redundant, safety critical infrastructure to avoid failure and degradation of service. The **bus system** operates with the computer aided dispatch and automated vehicle location system. **PAL operates** with a working call center and some on-line services to support reservations.

Mode	Definition
	Note: vehicle operations and maintenance are excluded from the modes of operations included in this discussion.
Degraded	Degraded mode for **rail** requires vehicles to travel at a slower speed or to stop operations until service is fixed. Degraded mode for bus operations may come from communications failures, customer facing equipment failures such as fare collection equipment, or weather disruptions. • When communications are degraded, real time information is not provided to the control center and consequently to the customer. • Weather disruptions slow the travel times of buses, but no special modes of operations occur. • Depending on the equipment, bus operations will proceed as normal. PAL reservations and service operations is a critical system.
Failure	Failure mode for **rail systems** requires that operations is suspended until corrections are made. Bus bridges are used to mitigate the disruption to service. Very rarely does the **bus system** go into failure mode. This may occur when the weather is so severe (snowstorm of over a 10 feet) that all operations are suspended in a particular geography until the vehicles can safely operate. As a critical system, PAL operations are only suspended when all services are suspended. Manual processes replace technology-based systems fail.

For traffic signal operations including pedestrian crossing, when a system degrades or fails, the traffic signal reverts to flashing warning and stop lights.

Adverse weather in Buffalo is a common occurrence and can impact the mode of operations. However, all the system owners report high degree of capability in terms of responding to typical weather events per their previously agreed plans/protocols. Unless it is for a significant snow event, agencies do not close streets or services. However, the challenge is in enabling that the sidewalks, shelters, and the pedestrian pathways are clear since the responsibilities are shared.

Another overall impact to the current system is construction and work zones especially those that affect the sidewalks or change access to transit services. If a work zone blocks sidewalk access or bus stops, the City of Buffalo coordinates with NFTA on appropriate mitigation strategies.

3.6 Operational Policies and Constraints

There are standard operational policies and constraints that are in place for the current services and infrastructure. Some specific policies and constraints of note in the current system include:

- Transit Policies and Constraints – These are based on the NFTA-Metro guidelines and procedures. NFTA is responsible for cleaning and maintenance of access to bus stops. NFTA updates elevator status, but escalator and elevator status are manually inputted right now. Transit workforce-related practices follow NFTA-Metro rules and regulations.

- Paratransit Policies and Constraints – To take a trip, travelers need to apply and be certified as eligible for NFTA-Metro's PAL. NFTA provides the PAL service using in-house staff and vehicles.

- Sidewalk Policies and Constraints – The city of Buffalo has specific requirements and constraints around improvements that involve easements, or maintenance. In particular, if construction is needed, the city of Buffalo needs to be involved in ensuring that underground utilities are notified and not affected. Note that the city does not clear snow of sidewalks. This is something required of homeowners and commercial property owners in the area. Similarly, NFTA does not clean bus stops, the municipality of where the stop resides is responsible for cleaning bus stops and shelters. However, NFTA is responsible for cleaning access to rail stations.

- Parking – Most of the off-street parking in the campus is in garages managed by the BNMC. However, on-street parking is allowed in the Fruit Belt neighborhood.

- Indoor Security and Access – Indoor pathways between BNMC buildings are governed by security and access restrictions defined by each building owner/operator. For example, certain pathways may require badged entry to a partner facility.

- Hours of Operations – Available transit services are bound by NFTA's hours of operation, ranging from around 5:30AM to 1AM, depending on the service and route.

- Budget and Staff – Common to any public agency, improvement to services and changes in staff are limited by existing and planned budget.

  AV Regulations – Currently, there is still evolving picture of automated driving system regulations in New York State. The SDS research at UB is restricted to private roads and for research use only. The most recent NYS legislation allows manufacturers of "autonomous vehicle technology," to apply to NYS DMV for a permit to test or demonstrate autonomous vehicles on New York roadways. The applicant is then required to submit the test/demonstration report to the Commissioner of Motor Vehicles. Moreover, the legislation requires vehicles that are being tested or demonstrated to 1) comply with all federal standards and applicable New York State inspection standards, 2) have a $5 million insurance policy, and 3) have a licensed driver behind the wheel. The steward of the AV, who must be adequately trained in the safe operation of the AV, must be in the driver's seat while a vehicle is operated on public highways, and be ready to take over the control of the AV when required.

4 Justification for and Nature of Changes

4.1 Justification of Changes

The city of Buffalo, the BNMC and local/regional transportation agencies in the area strive to provide safe and accessible transportation to all of their residents and visitors. However, they are challenged by old infrastructure and systems, incomplete and disjointed set of information, and a lack of communication and traveler information technologies. **All these issues and gaps in capabilities and services result in a transportation system that is not integrated and fails to provide a complete trip to travelers.** Integration of available data sources combined with additional data on accessible outdoor and indoor infrastructure paths and automated data on elevator escalator outages, with links to more dynamic mobility operations such as PAL and first mile/last mile operations will help create a tool to meet the needs of a complete trip for underserved communities.

The following subsections summarize the deficiencies identified through stakeholder engagements and the stated desires for changes, as well as rationale for these changes.

4.1.1 Summary of Current Deficiencies

Within and around the BNMC, there are general transportation and mobility problems, including traffic safety issues at street crossings, lack of accessible infrastructure in street rights of way, and lack of efficient and reliable circulation paths between facilities on the campus and surrounding neighborhoods.

While distances are short, pedestrian activity in and around the campus, especially from Fruit Belt and Masten Park neighborhoods, are challenging due to the inadequate infrastructure and accessibility issues, especially for travelers with disabilities, older adults or even travelers with temporary mobility challenges (like returning with groceries, or with double strollers)

Street crossings in particular can be significant barriers to people with disabilities and older adults, especially in older cities like Buffalo and around BNMC. Common problems include the collection of water, ice and snow at the bottom of curb ramps due to poor drainage; counter slopes at the bottom of curb ramps that make walking difficult and also cause wheelchair users to bottom out; broken and irregular pavement in the crossing area; the use of brick and cobbles that makes wheelchair use very uncomfortable; deterioration of tactile warning signals; and poor contrast of crosswalks with the street surface.

These problems have a direct impact people's ability to reach BNMC's facilities and get to their appointments on time, or even make the trip/appointment at all—this particular issue was highlighted during several interviews with stakeholders.

Furthermore, gaps in accessibility and usability listed above certainly have an impact on the travelers. These deficiencies are further exacerbated during winter, with sometimes serious impact on pedestrians, especially those who may have a disability. While not in the deployment area, one recent example is an accident that took place on Middlesex near Lincoln Parkway on December 25, 2020, where a couple (one of them in a wheelchair) was hit by a car while walking on the street since the sidewalk and curb ramps were impassable due to snow (WKBW, 2020).

For many of community residents who don't own or cannot drive their own vehicle, transit continues to be the primary mode of choice. In Buffalo, interviews with stakeholders repeatedly noted the frustration about how emerging mobility services (like transportation network companies) have not supported travelers with difficulties. Given the importance of transit and connectivity to transit, the ability to make a transit trip from door to door is not a nice-to-have but a must-have for the communities surrounding the BNMC.

4.1.2 Desired Major Changes

User needs gathering, stakeholder engagements, visual inspections, partner discussions have identified the following desired changes that support the proposed concept for a complete trip deployment. In general, the travelers and institutional stakeholders expressed a desire for:

- **Consistent, continuous trips to, from and in the BNMC area.**
  - A key aspect of inclusive and smart infrastructure is continuity–ensuring that there is an accessible and convenient path of travel to and from all destinations. Without continuity, there will be barriers to usability and safety for people with disabilities and inconveniences to other user groups. Another key aspect of inclusive and smart infrastructure is consistency. This means that elements of the infrastructure work the same and provide the same benefits throughout the target area. Consistency ensures awareness and understanding and is particularly important for people with mobility, sensory and cognitive limitations.
  - The current environment, as discussed Section 3.2, requires improvements in connecting traffic signal systems, communications infrastructure, sidewalk accessibility, signage, stop accessibility, and more, to provide continuity and consistency. In an area like the BNMC, continuity and consistency are critical for all users, particularly because a large proportion are visitors, not employees. Introducing new technologies into a physical environment will create novel experiences even for those familiar with the area. Thus, due to unfamiliarity with the area and novel technologies, both visitors and employees alike will be "disabled" even if they do not have clinical impairments.
- **Online and offline ways to receive real time information on services and infrastructure usability and accessibility.**
  - Real time information is an important component of trip planning and execution, particularly for travelers who are disabled and have no or limited access to internet. As such, real time communication of information through a comprehensive array of alternatives that includes online and offline visual, audio and haptic notifications, or a combination of, would allow travelers to understand

the current condition of their trip and how to best react to deviations from their original plans.

- Passengers desire early notification of bus arrival; this can include app based real time information or notifications, but for those who do not have smart phones, visual notifications that can be seen from a distance is highly desirable. The potential exists to use vestibules and shelter from nearby buildings as a means to improve comfort at bus stops in place of bus shelters or as a means to provide thermal comfort if shelters are not heated.
- Improved communication of information regarding usability and accessibility of services and the physical infrastructure (e.g., sidewalks and pathways to key destinations, bus shelters, and intersections) will enable the push towards inclusiveness.

- **Trip paths that are safe, accessible, and compatible with defined preferences and capabilities.**[2]
    - From a pedestrian perspective, this includes providing path that have reasonably leveled, slip resistant, smooth paths of travel. While this is important to all travelers, this is especially important to those who use wheeled mobility devices and walking aids, as well as and those who have difficulty maintaining balance and walking. The latter group includes people with prosthetic limbs, limitations of gait and loss of feeling in lower extremities.
    - Many pedestrians are unable to cross the street during the provided pedestrian crossing time. Pedestrians often delay entry into the street due to uncertainty about their ability to cross in time and also get stranded on islands in the center of the street. The latter exposes them unnecessarily to safety risks and discomfort from splashing in bad weather. Intersection technology that provides safe periods for pedestrian crossing can reduce conflicts between different modes of transportation. Although accessible pedestrian signals provide more safety for people with vision impairments, there are many enhancements to these systems that have not yet been adopted in the Main Street corridor. There is also a desire for proper orientation when approaching crosswalks. A visual inspection of the Main Street corridor identified many of the common problems with street crossings in the area. Many intersections in the area lack accessible pedestrian signals. VIA is located near the corner of Main and Best Streets. Thus, this intersection serves a large number of people who are blind or have low vision. The Middle Main Street project will introduce bike lanes that will increase the complexity of street crossings, especially for people with low vision and blindness and deaf pedestrians who cannot hear warning noises.

[2] Some of the infrastructure changes may require physical streetscape improvements that are outside the scope of this project.

- Furthermore, currently there are no accessible and safe loading zones or bus stops on the campus and there is a great deal of congestion at the hospital loading locations where passenger vehicles queue up to drop off patients. Thus, it would be desirable to add more loading areas to support shuttle use but also to draw other vehicles away from the congested entries and provide a safer environment for the drop off-to-building entrance portion of trips.

- **Integrated, flexible, demand-responsive, end-to-end transit options for the community.**
  - Currently, travelers have the capability to search from pre-trip information, such as schedules, directions, routes and maps, and even to book and pay for trips in advanced for services that allow to. However, these are not integrated, complete or comprehensive enough to provide adequate end-to-end services to traveler who are disabled in some way. For instance, PAL makes provisions to ensure that each passenger gets from his/her point of origin to his/her point of destination, requiring that PAL Operators escort PAL clients to and from the PAL vehicle when such assistance is requested. However, origins and destinations are defined from an outdoor perspective and not take into account the first/last feet of the PAL client's trips—i.e., passengers are left outside a building, but then may not have real time guidance on how to get to their true final destination (e.g., a doctor's office), indicating issues that relate to both indoor/outdoor navigation and transition between outdoor/indoor spaces.
  - Services are also being impacted by their current and expected growth rates, demanding improvements in operating efficiency and core capacity. Stakeholders requested a flexible demand-responsive micro transit service, in particular for vulnerable and underserved populations, between the Fruit Belt and BNMC (and within BNMC). There is also a clear need for feeders to the public transit system and a means to connect available (and new) mobility alternatives within the BNMC and surrounding communities.
  - Another major limitation to travelers is the lack of flexibility in some services. While PAL reservations can be made up to 14 days in advance, these cannot be made after 4:00 p.m. the day prior. This gives little flexibility to PAL users to make more spontaneous trips, or to make in route changes to their trips. Within the BNMC and surrounding areas, fixed bus and light rail routes fail to provide the necessary coverage and flexibility required to adequately service travelers within and around the BNMC area.

4.1.3 Rationale for Changes

The desired changes and the proposed system enable safe, supported and high-quality trips to a travel population that is heavily dependent on access to transit services for jobs, medical treatment and day to day services. Without the system, travelers with disabilities, older adults and low-income travelers (especially those without access to personal automobiles) will continue to experience challenges in sharing and engaging with the economic and social activity of the city.

4.2 Description of Desired Changes

The desired changes are described as user needs. User needs were gathered through an intensive round of interviews with end-user advocacy groups and agency partners.

User needs are defined using the following principles:

- Each need should be **Uniquely Identifiable**, with a unique number and title.
- Each need should describe a **Major Desired Capability (MDC)** in the system.
- Each need should be **Solution Free**, without any reference to technologies or approaches (exiting or proposed).
- Each need should **Capture Rationale** as to why it should be address by the new system.

For this project, the user needs are categorized into end-user related system needs and system owner related needs. End-user related needs describe what the system needs to do to support complete trip planning, execution and support from a user/traveler point of view. System owner related needs describe the needs for operations, maintenance and management that create the environment for the end-user needs to be met.

User needs are identified by the following nomenclature:

- UN – User Need
- Type of Need – E (End-User) or S (System)
- Sub Area – TP (Trip Planning) for example
- Need number – sequential numbering within the sub-area

For example, an end-user related system need under complete trip planning would be numbered as UN-E-TP-1.

4.2.1 End-User Related System Needs

The end-user related system needs are organized by the complete trip chain starting with planning needs, followed by trip execution needs and finally by travel support needs.

4.2.1.1 Trip Planning (TP)

4.2.1.1.1 Travel Needs

UN-E-TP-1. Spontaneous Trip: The system needs to provide the ability to execute spontaneous trips using public transit travel options based on user inputs of origins and destination. This allows travelers the ability to make unanticipated trips or undertake trips for which paratransit services are not available.

UN-E-TP-2. Coverage: While certain aspects of the system are limited to the BNMC campus, the system needs to be useful to users from outside the project boundary specifically around improving access to transit services information for the entire NFTA bus and rail network. This allows the system to support at least some aspects of trip making throughout Buffalo.

UN-E-TP-3. Increased Access. The system needs to increase access of surrounding community to BNMC partner facilities, services, and the transit facilities without the use of personal auto. This is necessary to support the residents in the neighboring community who are older adults or do not have access to a personal automobile.

UN-E-TP-4. Independence. The system needs to support independent travel by travelers with disabilities as much as possible. This is necessary to ensure that travelers feel supported by the system to achieve their own travel and personal objectives.

4.2.1.1.2 Travel Information Needs

UN-E-TP-5. Trip Planner: The system needs to offer an easy-to-use multimodal trip planner tailored to underserved communities that encompasses selected mobility options and door to door trip plans. For this project, underserved communities entail people who are:

- senior adults,
- low income,
- limited English proficiency,
- with dementia and other cognitive challenges,
- who are blind or have a limited vision,
- who are deaf or have limited hearing.

UN-E-TP-6. Integrated Multimodal Service: The system needs to be able to generate and execute multimodal trip plans to, from and around the BNMC campus that integrate with existing transit services. This allows travelers to see all the alternatives available to them (e.g., modes, times, and cost) and to quickly transition from one to another if the traveler desires or needs to, while optimizing the use of available capacity of existing and new systems.

UN-E-TP-7. Information Needs. The system needs to collect and integrate available data from external and internal sources to provide a complete trip plan. External and internal information includes:

- locations of accessible pickup / drop off zones,
- accessible facility entrances and exits,
- sidewalk obstacles and impediments,
- weather conditions,
- signalized intersections with pedestrian signals,

- and other information that support complete trip travel.

This ensures that trip plans and notifications are based on real time information on infrastructure, weather and services conditions.

UN-E-TP-8. Trip App: The system needs to offer an easy-to-use application that leverages the trip planner and enables successful execution of trips including the ability to support travel while offline (or without connectivity). This ensures that users can plan, book and execute trips through online/offline devices.

4.2.1.1.3 Accessibility of Travel Planning Services

UN-E-TP-9. Trip Accessibility/Compatibility: The system needs to provide services that are accessible and compatible to user based on their defined preferences. This ensures that travelers are presented with mobility alternatives that align with their preferences and capabilities. For instance, travelers with mobility devices are presented trips that take into consideration any necessary lifts, ramps and securement systems.

UN-E-TP-10. Assistive Technology Compatibility: The system needs to offer a trip planner that yields trip plans that are compatible with assistive technologies. Assistive devices include those that support/improve mobility (e.g., wheelchairs and walkers), cognitive, visual and hearing aids.

4.2.1.1.4 App/Service integration

UN-E-CTP-11. PAL Profile Integration: The system needs to integrate with PAL Direct to integrate traveler profiles based on their eligibility and preferences. This allows the PAL users to not create another account or re-establish eligibility.

4.2.1.1.5 Trip Booking

UN-E-TP-12. Shuttle Trip Booking and Reservation. The system needs to allow users to book/reserve a ride on a shuttle based on their preferences, location and origins/destination. This is necessary for a system user to use the shuttles to make the trip or use the service to connect to transit.

UN-E-TP-13. PAL Trip Booking: The system needs to allow a PAL-eligible user another way to book PAL trips based on the approved PAL trip policies and eligibility. This allows PAL-eligible users to not switch systems to book trips that may be outside the scope of the system.

4.2.1.1.6 Trip Costs

UN-E-TP-14. Cost to User: The system needs to provide options to the users that have comparable or lower costs to existing modes. This ensures equity across income categories and increases use of the system.

4.2.1.2 Trip Execution (TE)

4.2.1.2.1 Use of Transit and Shuttles

UN-E-TE-1 – Real-time Information. The system should provide real-time information of the arrival time for the transit vehicle to the user who is awaiting the trip. This ensures that users have real time information on the status of their trip.

UN-E-TE-2. Mobility Devices Access: Vehicles in the system need to include lifts, ramps and securement systems necessary for travelers using mobility devices (e.g., wheelchairs). This ensures that vehicles are accessible to all users.

UN-E-TE-3. (OPTIONAL) Seat Availability: The system needs to be able to assess whether there are available seats in the transit vehicles based on current use of securement systems as well as crowd size and other requirements (allergies, space requirements). This ensures that the system provides trip plans involving shuttles that account for occupancy.

4.2.1.2.2 Wayfinding

UN-E-TE-5. Pick-up and Drop-off Zones: The system needs to define a set of drop-off and pick-up zones for all the major partner facilities at BNMC for access to the facility by various types of disability. This would allow for specific paths directly to the appropriate entrance/exit that is necessary for the user. This is particularly important when the user is being dropped off by private services (like transportation network companies, TNCs) that may not be able to access the right drop-off point area due to congestion or other impediments.

UN-E-TE-6. Traveler Guidance: The system needs to orient users and assist them in their navigation (wayfinding) and destination finding through accessible path between selected transit stops and buildings within the campus. This enables people who are blind or have low vision to better identify the direction they need to travel. Guidance can be based on user preferences and can include turn-by-turn information.

UN-E-TE-7. Indoor Navigation. The system needs to direct travelers on accessible paths to/from within buildings within the campus. This enables people who are blind or have low vision to better orient, travel and confirm destination once inside the door of the facility. Guidance can be based on user preferences and can include turn-by-turn information.

4.2.1.2.3 Vulnerable Road User Safety

UN-E-TE-8. Safety: The system needs to direct users safely across intersections involving conflicts with vehicular traffic. This enables people who are blind or have low vision to be better supported while crossing intersections and provide additional time for crossing intersection for travelers who need it.

4.2.1.2.4 Notifications and Alerts

UN-E-TE-9. **Trip Notifications:** The system needs to provide real time notifications to travelers in haptic, audio and visual format. Notifications include, but are not limited to, turn-by-turn directions, estimated time of arrival (ETA), pick up/drop off locations, and next stop when using or waiting for a bus/shuttle/light rail. These reminders help reassure people with dementia and other cognitive challenges, as well as let passengers who are blind or have a visual impairment to get ready for boarding or alighting transit services.

UN-E-TE-10. Notification Preferences: The system needs to provide notifications that accommodates people's preferences and abilities. Preferences include, but are not limited to, frequency and level of detail of guidance/directions (e.g., step-by-step vs turn-by-turn), language, voice messaging, visual guidance, desired margin to arrive before appointments, upcoming stops, location tracking/guidance, and transit routes (e.g., lowest fare, fastest time, and fewer transfers). This ensures that the travelers are able to receive the information that is being conveyed.

UN-E-TE-11. Notification and Alert Priority. The system needs to have the ability to prioritize notifications and alert based on the impact to users. Higher priority notifications may need faster and more redundant ways of information transfer. For example, when notifications require immediate attention, (like vacating the light rail station due to an emergency), the system needs to be able to provide these alerts quickly and maybe all different forms (audio, visual, text) necessary.

4.2.1.2.5 Adverse Weather

UN-E-TE-13. Adverse Weather Operations. The system needs to support operations of services in adverse weather. While stakeholders in Buffalo are very experienced and capable in winter weather operations, several scenarios are possible due to adverse weather in Buffalo and systems needs to provide the ability to mitigate the impacts of weather on trip making. Scenarios of interest include:

1. Sidewalks, shuttle drop-off bus shelters not being passable due to delayed snow and ice clearance.

2. Roadway operations are compromised to due to snow and ice conditions.

4.2.1.2.6 Nighttime Travel

UN-E-TE-14. Nighttime Travel. The system needs to support nighttime travel needs for travelers. While hours of service for shuttle operations are not determined, other aspects of the system need to support traveler use during nighttime. This is necessary so that the wayfinding, indoor navigation, and other information services are available to travelers who will accessing the campus after sunset and work appropriately under diminished lighting.

4.2.1.3 Travel Support (TS)

4.2.1.3.1 Point of Contacts

UN-E-TS-1. Assistance: The system needs to provide a means for travelers to communicate with a trained and designated human operators at any point during the trip through telephone, mobile app, or in person, depending on the stage of their trip (e.g., at home planning, walking, within the shuttle, within a building). This ensures that travelers are able to communicate with a human operator in case of emergencies or even for additional support.

UN-E-TS-2. Matching Assistance to Services. The system needs to match traveler requests for assistance to the right operator based on their current location and preference on the trip. This is important that the support needs are addressed by the responsible entity and customer satisfaction is maintained.

4.2.1.3.2 Training

UN-E-TS-3. Traveler Training. The system needs to train users on using each and all aspects of the system. Training could include how to use trip planning, use transit and shuttle services, as well as the wayfinding and intersection movement assistance tools offered as part of the project. This will ensure that all users of the system have a clear idea on what is provided and what the limitations of the system.

4.2.1.3.3 Low-tech or no-tech access to the system

UN-E-TS-4. Low-Tech/Non-Smartphone Accessibility: Services used by the system need to be accessible through different non-smartphone interfaces (e.g., telephone, voice, text, symbol, etc.). This is necessary to support the different needs of travelers but also provide services for users that do not have access to smartphone or broadband technology.

4.2.1.3.4 Caregiver support

UN-ES-TS-5. Users External Authorized User: The system needs to be able to identify and allow access to authorized external users (e.g., caregivers and guardians). This ensures these authorized people can book trips for the designated traveler(s) and track/modify the trip while enroute.

UN-ES-TS-6. Caregiver Travel. The system needs to ensure that caregivers are not separated from the person they are accompanying and are charged the right cost of their trip under local regulations.

4.2.1.3.5 Service Animals

UN-E-TS-7. Service Animals: The system needs to compliant with policies to accommodate passengers with service animals. This is important to ensure that the system is inclusive.

4.2.1.3.6 Traveler Feedback

UN-E-TS-8. Crowdsourced Data: The system needs to collect data from its users (that opt-in). Data includes both performance and real time condition information. This is important to improve real time trip planning and execution, as well as to enable the assessment of the system's performance.

UN-E-TS-9. Satisfaction: The system needs to periodically gather customer satisfaction with information and travel services provided. This is important to assess of the system's performance as well as support continued engagement with the travelers.

4.2.2 System Owner Related Needs

These set of needs pertain to how the system needs to be set-up and developed to support the end-user needs. Areas of needs include aspects like system integration, safety, scalability, accuracy as well as the business needs for the various stakeholders involved in the system.

4.2.2.1 Systems Operations (SO)

4.2.2.1.1 System Integration

UN-S-SO-1. Travel Impact Info Integration: The system needs to collect current, planned and/or forecasted information that may impact accessibility, trip planning and execution, traveler information and operations. These include, but are not limited to:

- Traffic, Work zones, Incidents, Weather, Infrastructure and services capacity status (e.g., parking availability), New and existing transit services status (location, estimated time of arrival, delays and closures), and Infrastructure status (e.g., elevator and escalator conditions, sidewalk condition).

UN-S-SO-2. Intersection Movement: The system needs to integrate signal controller information from selected intersections and be able to provide hands-free intersection movement assistance to travelers. This would increase safety when crossing intersections for vulnerable road users around the BNMC.

UN-S-SO-3. Wayfinding Infrastructure integration: The system needs to integrate updated and/or new communication and information technologies that improves sharing information with travelers traversing on sidewalks and bus shelters. This ensures that travelers can receive information while at selected locations and be guided to their destinations as part of the complete trip.

UN-S-SO-4. Indoor Navigation Integration: The system needs to integrate with indoor wayfinding technology in partner buildings, particularly entrances, information/reception desks and bathrooms. This is necessary to ensure that travelers are supported through the last leg of their trip adequately and get confirmation of their destination.

4.2.2.1.2 System Use

UN-S-SO-5. Reporting Issues: The system needs to share real-time information with appropriate entities when travelers are reporting vehicle, facility or other system problems and emergencies. This would help minimize the consequences of undesirable travel events.

UN-S-SO-6. Offline Use: The system needs to allow reservations and access to the services offered if there is no or limited access to the internet or smartphones. For example, the system may provide travelers to hail a shuttle using a device that is available to anyone (not a personal mobile device) while at a designated shuttle stop. The device will need to comply with ADA regulations for travelers who are blind or have low vision to ensure that such travelers are familiar with the new system as it would resemble existing ones.

UN-S-SO-7 Opt in: The system needs to enable travelers to opt in to tracking services and to receive notifications. This ensures that travelers are in control of the data they share and receive.

4.2.2.1.3 Data Management

UN-S-SO-8. Data Management: The system needs to securely collect, store and share data on the performance of all of its components per agreed upon protocols and agreements. This would allow the project team to monitor and assess the system performance, as well as measure the benefits of the system.

4.2.2.1.4 System Security and Reliability

UN-S-SO-9. Hardware Characteristics: The system needs to use hardware that can withstand tampering and severe weather conditions that are commonly present in the deployment area.

UN-S-SO-10. Secure Software: The system needs to provide safe and accessible services and software that are secure by design and protects the privacy of its users. This is important as user will not be motivated to use the new system if they feel their personally identifiable information (PII) is not correctly handled and protected.

UN-S-SO-11. System Reliability: The system needs to be reliable so travelers can rely on its availability.

4.2.2.1.5 System Scalability and Interoperability

UN-S-SO-12. System Scalability: The system needs to be scalable geographically (additional regions) and demographically (more people using the system at the same time) in and around the project region. This would ensure that the system can operate and provide information to travelers as services and operational requirements continue to grow.

UN-S-SO-13. Open Architecture and Interoperability – The system needs to have an open architecture and be interoperable with existing systems and services. This would ensure that new and legacy capabilities and services can be integrated with the proposed system.

4.2.2.1.6 System Safety

UN-S-SO-14. Safety of Services. The system needs to improve safety for both the users of the travel and information services (like the transit and shuttle options) not only for the users but also for the non-users of the system (other pedestrian, vulnerable road users that are using the same facilities as the system users). Overall safety improvements especially in the BNMC region create more support for the system as well as increase the amount of non-single occupancy vehicle travel.

4.2.2.1.7 System Accuracy

UN-S-SO-15. Location Accuracy: The system needs to accurately track or geofence travelers using the turn-by-turn directions and notifications (when they opt-in) whether they are traveling indoors or outdoors and even when the system is offline. This accuracy is necessary to ensure that travelers are correctly located in the system and appropriate information is shared based on their preferences. Specific accuracy requirements will be developed in the design stage and build of the safety management plan.

UN-S-SO-16. Accuracy of Information Services: The system needs to ensure that information provided by the systems especially around wayfinding and intersection movement assistance do not create safety risks for the users due to reduced latency or misbehavior of information in the system. Specific accuracy requirements will be developed in the design stage and build of the safety management plan.

4.2.2.1.8 System Disruptions

UN-S-SO-17. Disruptions to the system: When due to external factors the system services cannot operate, the system needs to have a failure mode of operations that does not degrade safety of the traveling public. The failure mode of operations will vary based on the sub-systems.

4.2.2.1.9 System Performance

UN-S-SO-18 Impact on devices: The system should have non-noticeable effect on the operations of the users' devices for other needs (e.g., minimize mobile battery use and minimize background data collection). This is necessary to ensure that users do not see the CTP system as having an adverse impact on their use of devices during the duration of the trip.

4.2.2.2 Business Operations (BO)

4.2.2.2.1 Feasibility and Sustainability

UN-S-BO-1. System Operation Costs: The system needs to provide services that have operational cost comparable to or lower than existing modes. This ensures financial sustainability from the institutional perspective.

UN-S-BO-2. Agency Training: The system needs to have clear and comprehensive training modules for system operators. This ensures that agency operators know how to properly use and manage the tools and services provided by the proposed system both during the deployment and in the future.

UN-S-BO-3. Minimizing Service Duplication: The system needs to serve BNMC partner needs and enable their employee and visitor travel needs to be met without duplicating shuttle services. The system should be designed such at BNMC partner organizations do not need to create new duplicative services for travel in the campus.

UN-S-BO-4. Shared Use: The system needs to provide as much shared use of services as possible and not function like an extended taxi service. This is important for BNMC partners and system owners that system is seen as supportive of shared transit and not viewed as a premium ride hailing service that would create difficulties in long-term sustainability.

UN-S-BO-5. Filling Transit Gaps: The system needs to act as a first mile and last-mile (FMLM) service to increase the use of existing fixed route services including bus routes and light rail on the campus. This is necessary to ensure that NFTA and region’s investments in transit are maximized.

4.2.2.2.2 Day to Day Operations

UN-S-BO-6. Operations Reports: The system needs to report current operating conditions of the complete trip elements. This information is important to have full integration with their ongoing engagement with commuters and visitors to BNMC. This information may also feed in other traveler services that exist in the region.

UN-S-BO-7. Marketing Guidelines: The system needs to have clear marketing guidelines (e.g., ready-made templates, branding and program information) that can be used for outreach and recruitment. This is necessary to support recruitment and adoption of complete trip elements by underserved populations.

UN-S-BO-8. Operations Compliance: The system needs to ensure that operation of its components complies with agreed upon regulations, laws, and restrictions. This ensures that the system does not operate in violation of any private property, local, or state regulations.

UN-S-BO-9. Hygiene Protocol: The system needs to conform to and maintain a hygiene protocol that takes into consideration allergies of travelers (e.g., to dogs) and presence of germs, and that details the procedure and frequency of disinfection of the different components of the system. This important to build a safe and clean environment for travelers.

UN-S-BO-10. System Maintenance: The system needs to conform to and maintain a maintenance plan that details the procedures and frequency of maintenance of all of the system's components.

UN-S-BO-11. Construction Coordination: The system needs to monitor and collect information on the dates and times of construction projects that affect the streetscape, cross-sections, sidewalks and intersections in the corridor. This is necessary to ensure that the system is able to generate appropriate paths are feasible for travel as well as support any adjustments to other services.

4.2.2.2.3 Emergency Support

UN-S-BO-12. Emergency Report: The system needs to notify emergency and law enforcement personnel in case of an emergency on-board the vehicles in the system.

UN-S-BO-13. Law Enforcement Interaction Plan: The system needs to conform to and maintain a law enforcement interaction plan that describes how and who should be engaged around aspects of system operations. This ensures that law enforcement understands how to interact with different type of travelers in the event of a crisis, as well as to minimize justice interactions and avoid penalizations, especially of users.

4.3 Priorities Among Changes

Except for the needs deemed as optional, all needs listed in Section 4.2 are priorities and essential to the proposed system. However, the prioritization for implementation, especially the features of the trip planner will be done during the agile development process.

4.4 Changes Considered but not Included

Several changes were considered but not included in the proposed concept.

- Fare payment integration with proposed trip planner. Given NFTA's recent ongoing and anticipated fare payment system upgrades, the stakeholders felt that adding fare payment to the list of changes would be a complex undertaking as well as premature. Regardless, there may be techniques to include a hyperlink in the trip planner to access any third party or NFTA fare payment apps. This deep linking technique does not include integration of application programming interfaces (APIs) or software development kit functions, but rather provides a way to *call* another app that the customer stores on their smart phone (similar to how certain travel planning apps can call a transportation network company app)

- Self-driving shuttle only within campus – While the initial discussions around the concept focused on a circulator focused solely around the BNMC campus, stakeholder engagement revealed that this would not be a valuable addition to the community, but an on-demand flexible service serving the neighborhoods would be seen as an asset.

- A solely-SDS fleet serving the deployment –In lieu of a solely-SDS fleet, the concept includes a mix of human-operated and SDS vehicles for the proposed concept. The stakeholders noted that this would be a significant way to de-risk the project while ensuring that service patterns are understood clearly before investing in a full SDS fleet.

- Transit signal priority – While there is significant interest in transit signal priority in the region, the proposed concepts do not lend themselves to a signal priority-type application.

- All infrastructure improvements, including heated sidewalks and other sidewalk modifications that require special considerations, O&M costs and approval from City of Buffalo, are out of scope for this project — In discussions with stakeholders, while there was significant interest in considering more innovative materials and techniques to deal with winter conditions on sidewalks and near bus shelters, they were considered outside the scope for the project due to the relative newness and limited real-world experience.

- Extension of the shuttle and overall project area to encompass downtown Buffalo – In this phase, the stakeholders recommended a focus on the BNMC and the Middle Main area but there are clear opportunities to expand the proposed concepts to connect the BNMC campus to downtown. However, the expansion has to be seen as a complement to the investment in the fixed rail infrastructure and not competition.

4.5 Assumptions and Constraints

4.5.1 Assumptions

- The proposed concept assumes that there are commercial automated driving system providers that are able to service the proposed route(s) within area of deployment as part of their operational design domains and business models.

- There will be an available interface to the NFTA PAL system that allows for PAL rider eligibility, trip reservation and trip notifications.

- Return to work from COVID-19 and travel patterns stabilize during the deployment phases of the project and there are no significant changes to existing transit services.

- Intersection, sidewalks, and other infrastructure improvements in the proposed concepts can be coordinated with the Middle Main Corridor construction project.

4.5.2 Constraints

- The legislative and regulatory landscape around self-driving shuttles and automated vehicles may be beyond the control of the project.

- There are significant infrastructure-related needs identified by users around the quality and location of sidewalks, building bridges, pavement markings and other physical assets. Upgrading the physical infrastructure beyond limited items noted in the concepts are out of the scope of the project.

- Concepts around indoor navigation may have to be developed without direct integration to BNMC partner IT systems to minimize the risk of dealing with different software systems and practices between BNMC partner members.

- Travel needs to and from outside the deployment area may be unmet through the proposed concepts.

- Existing data source standards or specifications that are used by existing applications include:

    - NFTA GTFS and GTFS-r provided by NFTA on their bus and rail systems

    - ITE Traffic Management Data Dictionary v. 3 (using the Transcom profile SPATEL data feed (used by NITTEC)

- Dependence on the Middle Main project for streetscape, intersection and cross-section improvements at a crucial intersection for the project (Main & Best). Delays in this project may create challenges in accessibility around the intersection. However, they may also be an opportunity to showcase the value of the system in guiding travelers around the location of major navigational uncertainty due to construction.

5 Concepts for the Proposed System

5.1 Background and Scope

The 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 with the purpose of:

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 share in the economic development in downtown Buffalo.

To achieve these goals, the proposed system of interest includes 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
  - Trip Booking
  - Trip Planning
  - Trip Monitoring and Notifications
  - Geolocation and Mapping
  - Navigation
  - Real-time situation monitor
  - Performance metrics
  - Trip history/ledger
  - User Interface: Mobile application
  - User Interface: Web and IVR
- **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 the wayfinding and orientation for indoor and outdoor, provision of navigation and destination finding through information kiosks (Transportation Information Hub, TIH) and augmented communications technologies (Smart Signs), and intersection treatment for hands-off, pedestrian signal requests.

- **Performance Dashboard Subsystem** -- This subsystem measures and presents the performance of the system.

Figure 13 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.

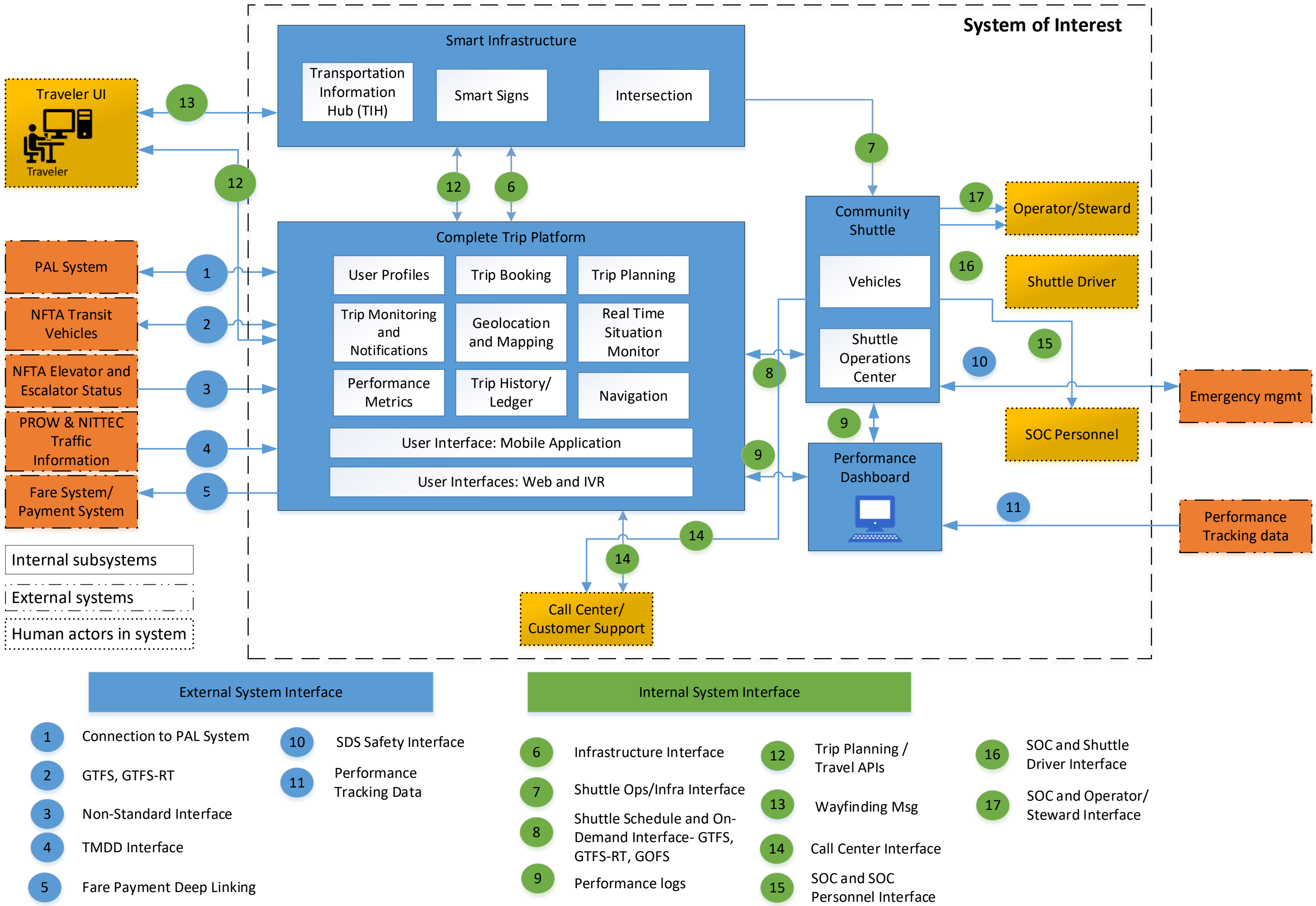


Figure 13. Buffalo, NY ITS4US Deployment Context Diagram with Interfaces.

Source: Buffalo, NY ITS4US

5.2 Description of the Proposed System

5.2.1 Complete Trips Platform Subsystem

5.2.1.1 Subsystem Description

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 micro transit shuttle services), personalize their trip preferences and customize hands-off 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. Interfaces between the System of Interest (SOI) subsystems are described in Section 5.2.5 and interfaces between subsystems and external systems are described in Section 5.2.6.

5.2.1.2 Functions

The functions contained in the components in the Complete Trip Platform subsystem, as shown in Figure 13, are described below:

USER PROFILES
The User Profiles functions provides users with a tool to register and customize their preferences for trip types based on user event triggers (including navigation, wayfinding and alert notifications), sensory alerts, trip and transition accommodations, in addition to shortest walking distance, fewest transfers, maximum walking distance, safest crossing zones, indoor navigation preferences, preferred mobility options, and other wayfinding technology interoperation. The user profile function also enables the user to opt in to share information among other systems such as NFTA PAL, community shuttle system, or other facility systems. The user profile function provides for the user to create, update or delete these preferences and other devices that are associated with the profile. The profile information is protected and preserved under the PII policies.

TRIP PLANNING
The Trip Planning functions enable a user to plan a complete trip from origin to destination, as well as the ability to update mobility options/service providers, trigger types, and other preferences based on the current trip. The trip planning function provides the user with the ability to review the turn-by-turn directions of a trip prior to traveling. Based on user preferences, the turn-by-turn directions may provision messages to indoor and outdoor wayfinding assets such as pedestrian crossing requests, door open and elevator hailing requests, and “you are here” locations.

TRIP BOOKING
The Trip Booking functions enable a user to reserve and book a trip with a service provider requiring pre-booking such as PAL and micro transit. Only registered, authorized users are eligible to use these services. Booking functions depend on the service provider. Among the data sent to the service provider include booking (and return booking), services required (e.g., caregiver or service animal, wheelchair, wheelchair type), cancellation, request for arrival time (and delay) messages, payment rules, and availability. The booking function will receive

confirmation and other booking details from the service provider, alert the user as needed (based on user preference), and store the information for user lookup.

GEOLOCATION AND MAPPING
The Geolocation and Mapping functions are two-fold: (1) collects and generates navigable graphs to support the trip planner based on fixed pathways (including existing maps such as the Open Street Map, GTFS, and GTFS-Flex) and their dynamic conditions (acquired through the real time situation monitoring function), (2) converts address and landmark locations to latitude and longitude.

NAVIGATION
The Navigation function generates a time / spatial graph that may be downloaded into a mobile app that can be used by the native app location awareness functions (including automated location tracking, wrong-side-of-the-street detection, geofencing, and activity recognition) to trigger messages with turn-by-turn directions including indoor navigation features such as stairs, elevators and escalators. The navigation function also includes information on interfacing with third party communications media to exchange information on wayfinding (such as messages about pathway and walk requests). Note: real time notifications are triggered by events that are either time or location based and are not associated directly with navigation (e.g., bus time of arrival, blocked path).

TRIP MONITORING AND NOTIFICATIONS
The Trip Monitoring and Notifications function continually monitors each user who opts in to tracking and monitoring their current location, revisits trip itineraries based on user trip preferences (provide re-routing when obstacles are detected), and issues triggers based on user notification preferences. The alerts and event messages are sent to the device(s) designated by their profile.

REAL TIME SITUATION MONITORING
The Real Time Situation Monitoring function collects and assesses real time information acquired from third party sources such as traffic, weather, transit operations, Shuttle operations, elevator/escalator operations, and other systems that monitor asset and infrastructure conditions and states. This function updates the fixed pathway graphs with dynamic conditions.

TRIP HISTORY / LEDGER
The Trip History and Ledger function stores information about user trip history, as well as logs all transactions and information received by the Complete Trip Platform subsystem.

PERFORMANCE METRICS
The Performance Metrics function provides Complete Trip Platform performance metrics on system utilization and user selections. Utilization and user selection includes Google Analytics measures (e.g., time viewing screen, number of hits on screen, etc.). Additional measures will include preference selections, trip types, and fidelity of using trip plans while traveling. The data is presented in a dashboard or in a table, in addition to being fed to the Performance Measure Dashboard to meet the Performance Measure and Evaluation Plan provisions. Data are summarized to remove PII from the measures prior to being shared with downstream systems.

USER INTERFACES: WEB AND IVR
The user interface (UI) functions provide universal access to users through multiple channels including voice (Interactive Voice Response (IVR) systems and call center) and text (web based,

font selection and sizing). The functions that are accessible include the following trip planning functions:

- Registering and updating user profile.
- Selecting and setting preferences for trip planning.
- Reviewing trip history.

USER INTERFACE: MOBILE APPLICATION
The mobile application functions include the ability of a user to download and synchronize trip planning functions (offered by the Web and IVR user interfaces), as well provision of the following:

- Real time notifications and events based on situational awareness when the mobile app is on-line.
- Geo-fencing calculations and stored triggers when the mobile app is off-line (see Navigation function)
- Communications between traveler mobile app and indoor / outdoor wayfinding devices.

In addition, the mobile application interconnection to other service providers or infrastructure assets may be implemented using a software development library (SDK), application programming interfaces (APIs) or deep linking to other apps stored on the user device.

5.2.1.3 Operational Environment

The environments in which the CTP subsystem will operate include a scalable cloud environment and UI devices (computer and smart phone). The app will be loadable from an app store.

Trip planning resources will all exist on a Virtual Private Cloud such as Amazon Web Services (AWS), and may include the following:

- Private (non-internet-accessible) subnet.
- Microservices that communicate with each other and with cloud services through the private subnets.
- Secure external access such as HTTPS connections.
- Network Load Balancer.
- Data / message encryption in transit (during transmission between system and end user) and at rest.
- Service oriented architecture.
- Native developed mobile app (using iOS and Android). The mobile app will be loadable from the Apple and Google app stores.

5.2.1.4 Modes of Operations

The Modes of Operation for the Complete Trip Platform are described in Table 9.

Table 9. Modes of Operations for the Complete Trip Platform Subsystem

Mode	Definition
Operational (regular)	Normal operating condition, the subsystem is operating as designed and functions during all hours of the day and is continually available, 24-hour per day, 365-day per year operation.
Reduced Availability	Reduced availability associated with planned maintenance impacting subsystem availability.
Mission Critical Errors (Severity 1)	A Mission Critical Error is defined as an error that renders the subsystem or a core set of functions unusable.
Severe Impact Errors (Severity 2)	A Severe Impact Error is defined as an error that severely impacts the core functions by slowing them down to perform outside of established performance requirements. A workaround might be available for the impacted core functions.
Minor Impact Errors (Severity 3)	A Minor Impact Error is defined as an error that affects subsystem operation or functionality in any way but is not a Critical Error or Severe Impact Error.
Maintenance	The condition of the subsystem where service is unavailable due to routine or unscheduled maintenance.

5.2.2 Community Shuttle Subsystem

The Community Shuttle Subsystem (CS) 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.

Figure 14 shows the subsystem context diagram for the CS Subsystem. Each of the above components has a number of functions, as indicated by the white or red rectangles enclosed within each box. The red color refers to functionalities that are pertinent to SDS, and the white color refers to functionalities that are needed for both the HDS and SDS. The figure also shows the interfaces between the subsystem components, the interfaces with the external or support subsystems (indicated by the orange rectangles), and interfaces with other subsystems of the Buffalo ITS4US deployment (indicated by the light blue color).

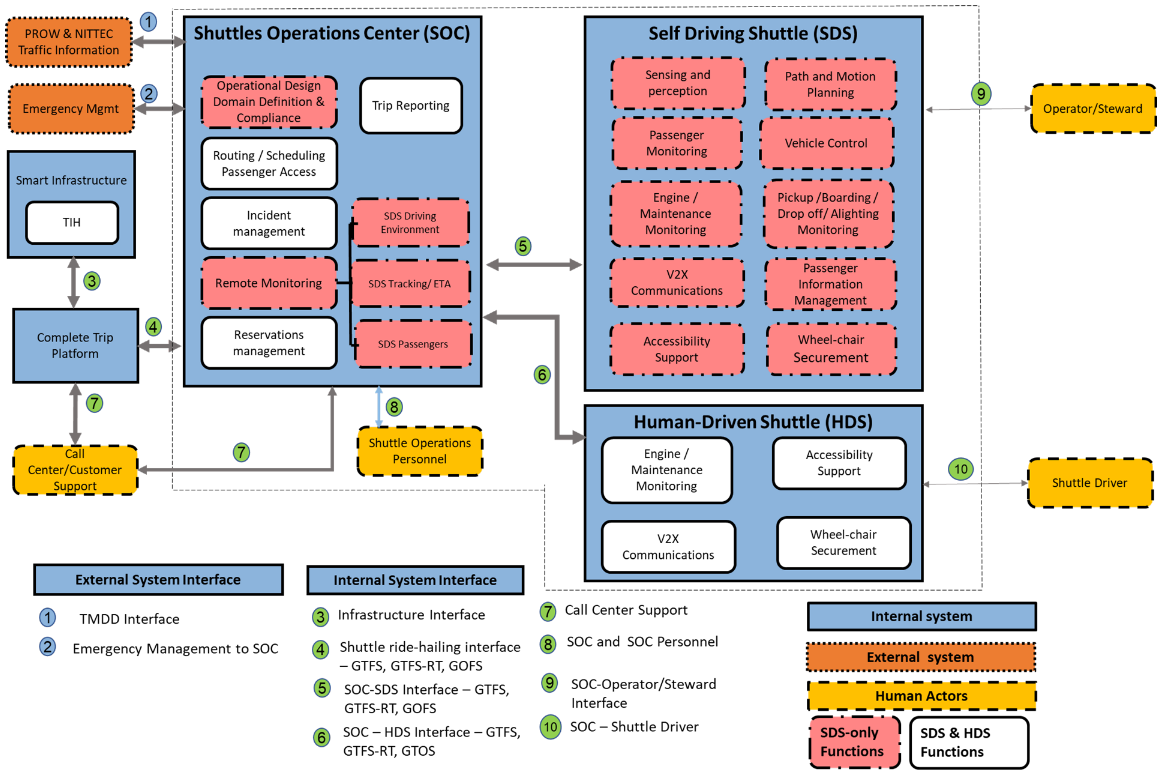


Figure 14. Community Shuttle Subsystem Context Diagram.
Source: Buffalo, NY ITS4US

5.2.2.1 Subsystem Description

The CS consists of a fleet of SDS and HDS that will be used to provide demand-responsive transit service connecting the Fruit Belt neighborhood and BNMC, thereby helping address the first- and last- mile challenge. The subsystem will provide Fruit Belt residents with access to the campus's healthcare services and employment opportunities, as well as the many transportation assets on the campus (i.e., the two metro stations and the several bus stops on campus). While the SDS will be designed to operate in a manner sensitive to travel demand, its operations will be constrained to a pre-defined route consisting of selected streets within the service zone that satisfy the SDS ODD, and travelers will be allowed to get on- or off- the SDS at designed pick-up and drop-off points. Demand-responsive in the context of the SDS component of the community shuttle subsystem thus means that the shuttle will be allowed to skip pick-up/drop-off locations where there is no demand and will not have a fixed or pre-defined time schedule.

The CS subsystem will also include HDS because a certain subset of our population of interest may not be able to utilize the SDS. This subset includes, for example, individuals who have mobility challenges in terms of getting from their place of residence to the closet SDS designated pick-up locations, or individuals who would feel safer, or would prefer, riding in a human-driven vehicle rather an autonomous one. For those individuals, an HDS, providing door-to-door on-demand mobility would be the better option.

The inclusion of HDS, along with SDS, also provides an alternative mode of transportation when the operations conditions go beyond the SDS ODD (e.g., during severe inclement weather, significant road work, and complicated road geometry). In addition, the inclusion of the two types of vehicles would:

1) Allow the project to contrast the pros and cons of AVs vis-à-vis human-driven vehicles.

2) Provide insight into the business case for using AVs within the context of a community shuttle system and especially for vulnerable and underserved populations.

3) Offer an educational opportunity for the community to learn about AVs thereby increasing public acceptance of, and confidence in, the technology over time.

4) Lower the risk of this subcomponent of our project, given some measure of skepticism that still exists among a sizeable portion of our society toward AVs, along with the current regulatory environment governing AVs which is still restrictive of some aspects of AV operations.

The envisioned service area for the proposed community shuttle fleet is shown in Figure 15.

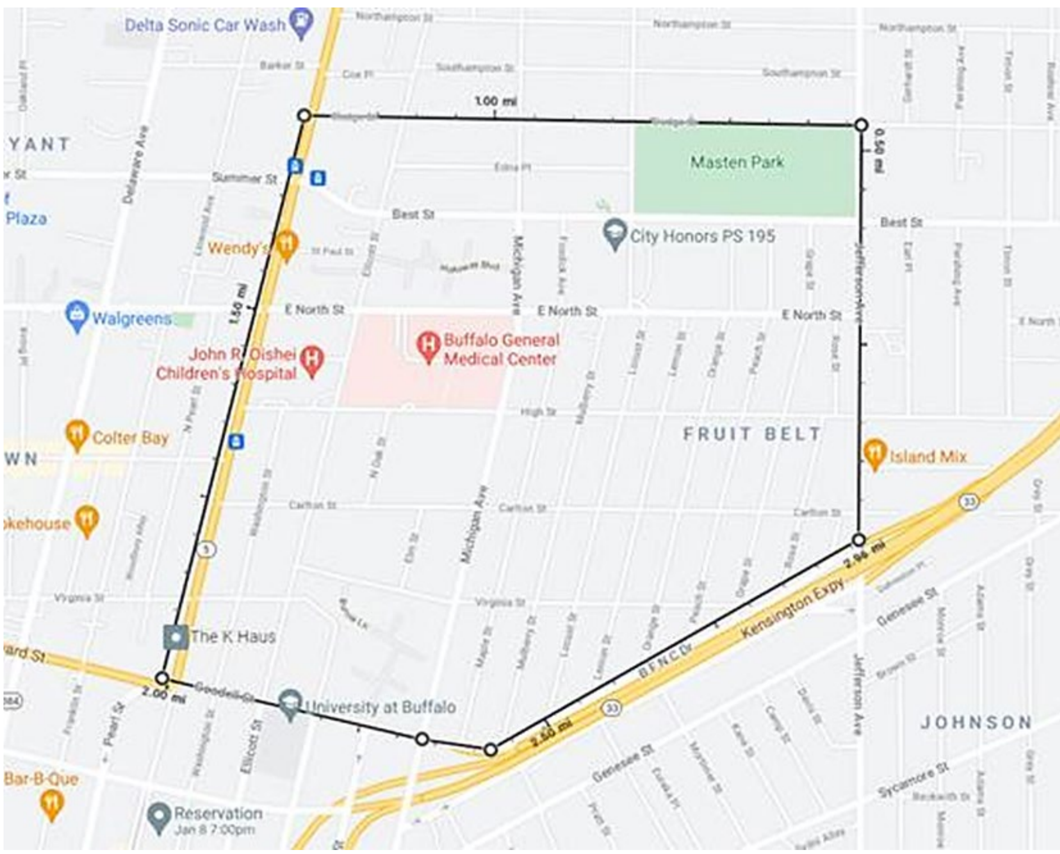


Figure 15. Proposed Service Area for the Community Shuttle.
Source: Buffalo, NY ITS4US

Users of the community shuttle register with the CTP, and once they register, they are able to summon the shuttle through the CTP.

In doing so, they can use any of the four user interfaces of CTP—i.e., the TIH (see 5.2.3.2.1), web, phone or mobile app (see 5.2.1.2)—depending upon their preference and access to internet. Through CTP, travelers would be able to indicate the origin of their trip, the pick-up time, as well as the final destination.

The SOC will manage all calls for services and will track the status of each vehicle in the CS fleet (in terms of its location, available seating capacity, ability to meet the accessibility needs of the user, its currently assigned route, etc.). Once it receives a call for service, the SOC will identify the available service/vehicle combination (on-demand HDS and/or SDS) to satisfy the request, and will return this information back to the CTP, where these options will be ranked and presented to the traveler.

Ranking will be based on 1) traveler's preferences and abilities as specified in the traveler's user profile registered within the CTP system; 2) earliest time when the shuttle can pick-up the traveler; and 3) the distance between the traveler's origin and destination and the nearest pick-up and drop-off locations of the SDS.

The vehicles of the CS subsystem will be allowed to serve more than one customer simultaneously (e.g., customers whose origins/destinations can be easily chained along the vehicle's route, and whose requested time of service fall within allowable time windows).

Analog to human shuttle drivers, Human stewards will always be present onboard the self-driving shuttles during operations. Those stewards will be primarily responsible for monitoring the safety of the SDS shuttles and performing emergency and non-emergency stopping of the shuttle whenever this is needed. They will also be responsible for performing the daily SDS inspection, and for documenting and reporting any hazardous situation that arose during operations. They will be trained to intervene if any emergency situations arise involving a passenger on-board the shuttle. In addition to the human stewards, and to improve safety as well as public acceptance, the SDS fleet will be remotely monitored by human operators in the SOC. This will enable the operators to ensure the safety of the passengers onboard the SDS, especially those with disabilities who may need special help with securing a wheelchair, or if an emergency arises during the trip.

5.2.2.2 Functions

The functions of the three Community Shuttle services including SDS, HDS, and SOC subsystem are described below.

5.2.2.2.1 SDS Functions

Sensing and Perception: This function allows the SDS to be aware of its surrounding environment and to identify any obstacles or hazardous situations it needs to avoid (i.e., situational awareness). It also enables the SDS to estimate its location with great precision (i.e., the localization function). Sensing and Perception typically involves fusing the measurements from a wide array of different sensors onboard the AV, combined with state-of-the-art object identification and classification algorithms to process and comprehend the environment around the vehicle, in real-time. An SDS may also need assistance from infrastructure-based localization devices such as a Real-Time Kinematic (RTK) base station, to correct errors in the GPS readings of SDS, along with a high-definition map, to achieve a sufficient localization precision. Infrastructure based sensors, such as a camera and a LIDAR, can also help eliminate occlusion and improve perception.

Path and Motion Planning: This function uses the information provided by the perception and sensing function, as well as a high-definition map, to determine an optimal trajectory for the SDS to follow. The optimal trajectory will indicate not only the specific route communicated to the vehicle from the SOC in order to pick up or drop off passengers, but also parameters such the SDS vehicle and velocity. In doing this, this function will take into account the predicted state of the SDS and other dynamic objects in the environment.

Vehicle Control: This function is responsible for tracking and adhering to the optimal trajectory determined by the path and motion planning function. It does so by controlling the throttle, brake and steering of the SDS.

Pickup/boarding and Drop-off/Alighting Monitoring: This function is responsible for monitoring the passengers as they board and alight from the SDS. Monitoring is needed to ensure that the passengers have safely boarded (or alighted) the shuttle before the shuttle closes the door and moves.

Passenger Monitoring: The passenger monitoring functions will allow the vehicle to monitor the safety of the passengers onboard. This includes ensuring that a passenger on a wheelchair is properly secured, and that older adults and passengers with disabilities are properly seated. The function is also responsible for detecting any emergency that arises among the passengers while enroute and notifying the SOC about the emergency.

Engine/Maintenance Monitoring: This function is responsible for monitoring the “health” of the *cyber* and *physical* elements of the SDS, which includes the sensors and software components of the sensor and perception, planning and control functions, the shuttle’s engine, the vehicle to everything (V2X) communications functions, the accessibility support elements (e.g., the ramp, the lift), and the wheel-chair securement mechanism. The function identifies the needs for maintenance and repair and would not allow operations if any critical element is not functioning properly.

V2X Communications: This function is responsible for establishing a communications channel between the SDS and 1) the SOC, 2) the infrastructure and 3) riders (e.g., facilitate the boarding and alighting process, authenticate that the rider is a registered user, and interface with health monitoring devices such as pacemaker, hearing aid, smart phones and smartwatches).

Passenger Information Management: This function will be responsible for indicating to riders of the SDS the progress of the trip by providing information (visual and audio) about environment surrounding the vehicle including: 1) Location, route, certain landmarks; 2) accidents, incidents; and 3) Deviations from route or why the ride may be stopping. The function will also provide auditory and haptic notification of estimated time of arrival and when the SDS is near the pickup/drop-off location. This is important as it would let the passengers with visual impairments to get ready for boarding or alighting the shuttle. Moreover, the SDS will have on-board monitors to display current location on a map display and show status indicators for normal operation.

Accessibility Support: This function includes the mechanism needed to support the boarding and alighting of persons with disabilities onto and off the SDS. The mechanism may include automatically deployed doors and ramps, reconfigurable seating, and storage spaces to meet passenger space clearance and mobility needs, and multi-modal (visual and auditory) exterior communications with pedestrians, and interior communications with passengers that enhance safety and support wayfinding.

Wheelchair Securement: This function will include the mechanism that would allow a rider with mobility impairment to secure her/his wheelchair onboard the vehicle. The function will also be responsible for notifying the SDS that it is OK to move.

5.2.2.2.2 *Human-Driven Shuttles (HDS)*

HDS Engine/Maintenance Monitoring: This function is responsible for monitoring the “health” of the HDS, the accessibility support elements (e.g., the ramp, the lift), and the wheel-chair securement mechanism. The function identifies the needs for maintenance and repair and should not allow operations if any critical element is not functioning properly.

V2X Communications: This function is responsible for establishing a communications channel between the HDS and the SOC.

Accessibility Support: This function includes the mechanism needed to support the boarding and alighting of persons with disabilities onto and off the SDS. The mechanism may include automatically deployed doors and ramps, reconfigurable seating and storage spaces to meet passenger space clearance and mobility needs, and multi-modal (visual and auditory) exterior communications with pedestrians, and interior communications with passengers that enhance safety and support wayfinding.

Wheelchair Securement: This function will include the mechanism that would allow a rider with mobility impairment to secure her/his wheelchair onboard the vehicle.

5.2.2.2.3 Shuttles Operations Center (SOC)

As mentioned in section 5.2.2.1, the SOC is the third major component of the CS Subsystem that will be responsible for overseeing, controlling, and managing the operations of both the SDS and HDS. The decision of who will be in charge of the center will have to wait until the details of the CS subsystem are further defined in the later stages of the project. The key functions that SOC will provide are listed below.

Operational Design Domain (ODD): This function will be responsible for defining the elements that make up the ODD for the SDS, as well as monitoring whether a given scenario satisfies those elements and would thus allow the operations of the SDS in autonomous mode. The elements of the ODD would include such things as the roads that the SDS is allowed to use, the road network (i.e., mapping, number of lanes, rules of the road), infrastructure support (e.g., connectivity), weather conditions, lighting conditions, amongst others.

Routing/Scheduling Passenger Access: This function is responsible for receiving a call for service request from CTP, determining the available service/vehicle combination that can be used to satisfy the travel request, communicating the identified service/vehicle type options to the traveler via CTP, receiving the traveler choice from CTP, calculating the optimal route from the location of the identified shuttle (which was selected to the provide the service) to the service call, and estimating the time of arrival at the service request. The function will also be responsible for managing passenger access to the community shuttle.

Incident Management: This function will receive information incidents along the path of the SDS, or incidents involving the SDS itself, and managing such incidents through the appropriate measures which will include notifying authorities, suggesting an alternate route, and updating expected times of arrivals.

Remote Monitoring: This function will implement remote monitoring of the following two elements:

- *SDS Tracking and Estimated Time of Arrival (ETA):* This function will allow the SDS fleet Center to track the location of the SDS fleet in real time and based on this along with the planned schedule and recommended route, will estimate the ETA for the SDS.

- *SDS Passengers:* This function will monitor the passengers on board the SDS and will enable the SDS fleet Center operators to communicate with the SDS passengers in case of emergencies.

Reservations Management: This function will manage the processes by which travelers may be able to reserve the SDS to satisfy one leg of their trip. The function will then confirm the reservation and provide the traveler with the ETA of the SDS, as well as the location of the pickup.

Trip Reporting: This function will be responsible for collecting all the trip-related information which will support the evaluation of the SDS operations and will support the calculation of the appropriate performance metrics. The function will keep track of any challenges or problems encountered during the trip, any cases that required the human stewards to take over the control of the shuttle, and any accidents or near-accidents that were about to occur.

5.2.2.3 *Operational Environment*

The environments supporting the micro-transit subsystem will include the following:

- V2X technologies will be needed to support communications and information exchange between the micro-transit vehicles (whether human-driven or autonomous) and the SOC.

- V2X will also be needed to support communications between SDS and traffic signals.

- The routing and scheduling algorithm of the SOC will require cloud and computing resources, and will operate within a scalable cloud environment, such as Amazon Web Services (AWS).

- SDS may need the support of a Differential GPS RTK stations for precise positioning.

- SDS may also require support from infrastructure-based or roadside sensors to improve performance during challenging operating conditions (e.g., inclement weather, bad visibility).

- SDS will require high-accuracy 3D Maps to support localization. These 3D maps are typically generated by driving the SDS or AVs over the geo-fenced area where the SDS will be operating and collecting the required data using the SDS suite of sensors.

5.2.2.4 Modes of Operations

Table 10 details the mods of operations for the Community Shuttle subsystem under regular, reduced, levels of severity and maintenance scenarios.

Table 10. Modes of Operations of the Community Shuttle Subsystem.

Mode	Definition
Operational (regular)	Normal operating condition, the subsystem is operating as designed and functions during the prescribed hours of operations.
Reduced Availability	Reduced availability associated with planned maintenance impacting subsystem availability.
Mission Critical Event (Severity 1)	A Mission Critical event is defined as an event that renders the subsystem or a core set of functions unusable. Examples include failure of the communications system between the vehicles and SOC, major problems with core algorithms (e.g., the scheduling and routing algorithm), or a significant weather event such as a major snow or ice storm. Under such circumstances, the whole subsystem, including both HDS and SDS, may not be able to operate.
Major Impact Event (Severity 2)	In this case, a major component of the subsystem fails, resulting in an event that severely impacts the core functions of the subsystem, by slowing them down to perform outside of established performance requirements. A workaround might be available for the impacted core functions. For example, if the SDS experience an error critical to their operations, one may still be able to operate the traditional human-driven vehicles. In that case, the mode of operations for the Community Shuttle Subsystem would be degraded. This may also be the case when inclement weather conditions for example prevent the safe operations of the SDS, but still permits the safe operations of HDS.
Minor Impact Event (Severity 3)	A Minor Impact Event is defined as an event that affects subsystem operation or functionality in way less severe compared to either a Mission Critical Event or a Severe Impact Event. Given the redundancy built in several aspects of the Community Shuttle Subsystem, there should be ways to keep the subsystem operational under such circumstances but with reduced availability. For example, a SDS has a whole suite of sensors for sensing and perception. Given this, the SDS may continue to operate if only a single sensor fails for example.
Maintenance	The condition of the subsystem where service is unavailable due to routine or unscheduled maintenance.

5.2.3 Smart Infrastructure Subsystem

5.2.3.1 Subsystem Description

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., as shown in Figure 16 with the red dots. Wayfinding in and transitioning between indoor and outdoor environments will be seamless. Trip planning and navigation functions will be provisioned through the CTP, with the wayfinding 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. Several improvements described in Appendix B will 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.

To provide a comprehensive concept of the Smart Infrastructure Subsystem, this section discusses the system-based functions needed to support the subsystem. In addition, the operational environment and modes of operations associated with subsystem components are also described.

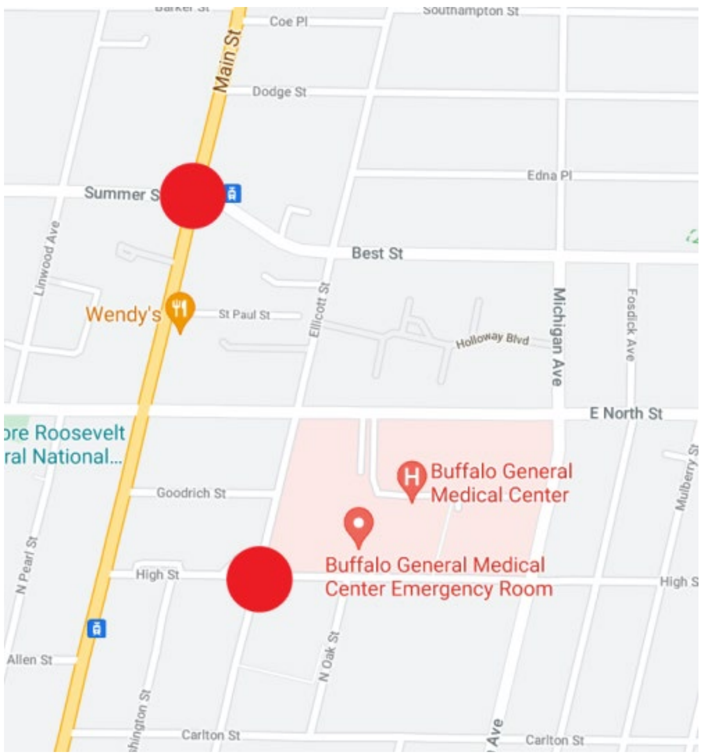


Figure 16. Intersections selected for improvements (red dots).
Source: Google Maps

5.2.3.2 Wayfinding

The wayfinding function is enabled by two major components: (1) the TIH and (2) the Smart Signs as shown in Figure 17. This sub-subsystem provides travelers with CTP functionality using an interactive web-based component (see Interface #12), and wayfinding and navigation support for several environments using the Smart Signs. Smart Signs are broadcast beacons that interface with the CTP navigation functions to locate a traveler's waypoint using commonly available communications technologies (e.g., Bluetooth) and user interface methods in indoor and outdoor environments. Both the TIH and Smart Sign form factors and operating requirements will support the conditions in which they are deployed. (Note: both the form factors and operating conditions will be specified in the requirements and finalized during the design phase).

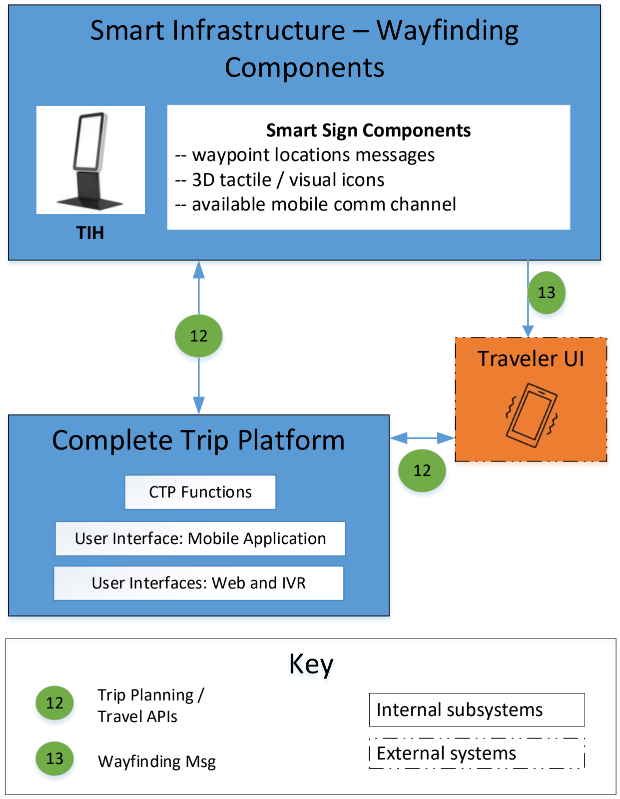


Figure 17. Smart Infrastructure – Wayfinding Context Diagram.
Source: Buffalo, NY ITS4US

5.2.3.2.1 Transportation Information Hub

The TIH provides the same trip planning and wayfinding information as the CTP. People can access their CTP account, generate a trip plan, save a trip plan, download a plan to their smart phone, request navigation directions and notifications, and more. The TIH will be preloaded with deployed location information and provide detailed information on the offices, centers and platforms in a facility including NFTA station platforms, medical labs, offices and more. The user interface will be set up to provide priority information related to the location deployed. For example, if at a bus shelter, notification information on the next bus destination and estimated time of arrival may be scrolled or provided as opt-in broadcast messages, while in a building or NFTA station, the TIH may scroll or broadcast information on elevator / escalator status.

The TIH will provide multiple types of accessibility channels through an interactive web browser, interfaces to audio, three dimensional tactile features and visual icons. The form factor will be fully accessible to people with ambulatory, visual and auditory disabilities. The system will be available to people without a phone or smart phone, in several languages, and augmented with common icons.

The TIH will also provide instructions on how to access the Smart Signs and provide the services to test the connections (see 5.2.3.2.2).

5.2.3.2.2 Smart Signs

Using commonly available communications technologies already deployed in mobile handsets, low-cost beacons will be deployed in signs that support waypoint locations (for orientation) at key locations in indoor and outdoor spaces. These beacons will provide location information for digital wayfinding integrated with the CTP mobile app navigation functions, and also physical tactile features (to support people without smart phones but who are blind or have low vision), audio messages, and visual icon features (to support people with cognitive disabilities and LEP populations). The beacons will broadcast simple orientation information, such as "2nd floor, hallway 12, right to hallway 13 and Offices 212, 214, 216, left to hallway 14, Offices 211, 213, 215." (Note: the details will be developed during the design phase.)

The Smart Signs also include multiple types of accessibility channels including the electronic wayfinding broadcasts interfaces to the CTP mobile app, interface to mobile app or hearing aid, and physical tactile and icon symbols.

The specific locations where these Smart Signs will be deployed will be determined during the design phase in coordination with the planned physical improvements to key intersections, sidewalks, bus stops and shelters, and facilities (see Section 5.2.3.4).

5.2.3.3 Intersections

The Intersection function will interface to standardized traffic and pedestrian signal controllers, as detailed in Figure 18 (see Flow 6). This function is enabled by two key components, Signal System and Ped-X Request Gateway, defined below.

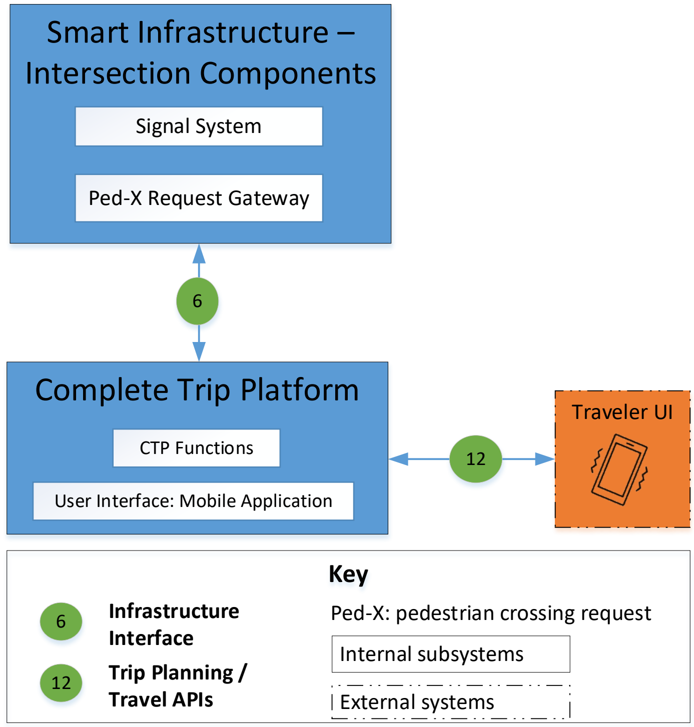


Figure 18. Smart Infrastructure – Intersection Sub-Subsystem
Source: Buffalo, NY ITS4US

Signal System. A gateway that receives and requests crossing actualization and provides countdown information to pedestrians will be included in the subsystem. (Note: the interface may be implemented as a direct request between the Traveler UI and intersection, or as a center-to-center interface from the CTP to the signal controller.) The CTP will track the traveler; when near an intersection crossing on their trip plan (based on the traveler's preference for hands-off actualization), the CTP will trigger a request for pedestrian signal to cross the street on their trip plan.

Ped-X Request Gateway. This gateway receives a CTP generated message using the hands-off request message selected by a traveler on their trip plan. The request will behave in a similar fashion as a request button except for several additional features:

- The message can be received by any gateway in the intersection to request the specific street to cross.
- The message will include the street to be crossed (e.g., at High and Ellicott, if pedestrian wants to cross Ellicott, the message includes the cross street – Ellicott or a numeric equivalent).
- The message will include the average traveler crossing speed based on their CTP preferences.

The gateway serves as a conduit to exchange information between the CTP mobile app and pedestrian signal request. Information channeled from the pedestrian to the signal system includes the request information, while information from the signal system to the traveler includes time to walk and countdown to cross the street.

5.2.3.4 Support Environment

Physical improvements to the infrastructure will contribute to support the Smart Infrastructure (and the CTP subsystem). The improvements will provide better routing and service options with integration of better accessible paths, paths to accessible entrances, safer signalized crossing, shelters that protect waiting travelers from the weather. Improved physical infrastructure related to the path, facility, transit stop / shelter and intersection will be incorporated into the CTP routing algorithms with higher accessibility scores than ones that have not undergone improvement. The result will provide greater accessible trip plans to travelers.

5.2.3.5 Operational Environment

The form factors and operating environment of each of the components will be compatible with their deployed environment. While all components will need to meet ADA and safety provisions, outdoor deployments will be subject to harsher weather conditions including humidity, waterproof, extreme cold and heat, and therefore, need to address specific operating and material codes, regulations and standards. In addition, these systems will need to be reviewed for multi-layered security feature from their physical security to cyber security provisions.

5.2.3.6 Modes of Operations

The modes of operation for these subsystems are highly dependent on operations of the CTP. To that end, the modes of operation follow CTP modes of operations (Section 5.2.1.4) and the integrated modes of operations (see Section 5.5).

5.2.4 Performance Measure Dashboard Subsystem

5.2.4.1 Subsystem Description

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. 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.

5.2.4.2 Functions

The Performance Measurement Dashboard subsystem will be implemented using a three-tier architecture – data (data tier), analytic processes (processing tier) and access / visualization channels (presentation tier).

Data Tier. The data tier will store or ingest data from the other subsystems and external systems as needed (defined in the Performance Measure and Evaluation Plan (PMEP) and subsequent design documents). In addition, metadata management will be included in the data tier to ensure data integrity. The data tier will ingest operational, maintenance, and performance summary data from each subsystem. Types of data that may be collected will be driven by the PEMP. These may include:

- CTP method(s) of utilization and user selections.

- CTP traveler trip plan preferences.
- CTP, traveler histories of trips planned, trips booked, and trips actually made. The traveler history data will be analyzed in the Processing Tier to create a variety of aggregate measures available in the Presentation Tier.
- Shuttle utilization, hailing source, number of trips, miles traveled.
- Shuttle operations, including incidents and delays.
- Infrastructure interaction with CTP.

Processing Tier. The processing tier will provide services to curate (e.g., remove PII), transform, parse and query data stores to generate performance and aggregated measures. A user authentication function will provide access to users of different security levels. Security and privacy provisions will be implemented to protect, store and archive information.

Presentation Tier. The access and visualization channels will include a web-based dashboard showing key system performance measures as well as a data portal that will provide access to data feeds, API and query capability for authorized users. As noted in the Data Management Plan (to be developed during the project), data used by this subsystem will be anonymized to ensure all personal information is stripped from the data sets prior to being stored by the subsystem.

5.2.4.3 Operational Environment

The operational environment will enable accessibility to partner organizations as well as to the public (as specified in the PMEP and compliant with the Data Management Plan).

5.2.4.4 Modes of Operations

The Modes of Operation for the Performance Measure Dashboard Subsystem are described in Table 11.

Table 11. Modes of Operation for Performance Measurement Dashboard Subsystem.

Mode	Definition
Operational (regular)	Normal operating condition, the subsystem is operating as designed. The system functions during all hours of the day and is continually available, 24-hour per day, 365-day per year operation.
Reduced availability	Reduced availability associated with planned maintenance on any of the subsystems that feed the Performance Monitoring Dashboard Subsystem. It also represents limited availability of data or processes incorporated in the subsystem.
Failure	Failure mode is associated with failure of the support environment on which the subsystem depends, that include the cloud platform or communications access to processes and channel access methods.

5.2.5 Internal Subsystem Interfaces

Table 12 presents the types of internal interfaces are expected to be used to share information within the system of interest.

Table 12. Internal Interfaces of the System of Interest.

#	Subsystem	Subsystem	Description
6	Intersection (Smart Infrastructure)	Complete Trip Platform	Request-response from the CTP mobile app to the Intersection requesting pedestrian signal crossing (see Use Case #10, Section 6.4.1)
7	Shuttle Operations Center	Smart infrastructure	Data feeds that describe pick-up, drop-off locations, fixed route shuttle stops and related construction and access to locations.
8	Shuttle Operations Center	Complete Trip Platform	Static and dynamic information on shuttle schedules and operations. These include: Fixed Route Shuttles: GTFS, GTFS-RT Micro-transit Shuttles: GTFS-Flex (optionally GOFS).
9	Complete Trip Platform / Shuttle Operations Center	Performance Dashboard	Performance data shared from the CTP and SOC subsystems. Types of data include rip plans and executions, user preferences and other log files that provide insight into traveler usage and utilization of Services.
12	Complete Trip Platform	Traveler UI / Wayfinding (Smart Infrastructure subsystem)	Static and dynamic information and interactive forms that supports the provision of trip planning, wayfinding and navigation using the TIH and Smart Signs using CTP platform functions. Crowdsourced information provided by users of the CTP access channels (web, mobile and call center) on trip conditions and obstacles to travel along indoor and outdoor pathways.
13	Wayfinding (Smart Infrastructure)	Traveler / Traveler UI	Orientation and wayfinding signals and messages provisioned by the Smart Sign components in the Wayfinding sub-subsystem.
14	Call Center	CTP and Shuttle Operations center	Interface to connect with a customer support person to support phone access to services both for CTP as well as community shuttle. The call center may be part of existing entities or new
15	Shuttle Operations Center	Shuttle Operations Personnel	Practices and policies around the interface of shuttle operations personnel and the SOC
16	Shuttle Operations Center	Shuttle Driver	Communications, practices and policies between the SOC and the driver of the human-driven shuttle

#	Subsystem	Subsystem	Description
17	Shuttle Operations Center	Operator/Steward	Communications, practices and policies between the SOC and the driver of the human-driven shuttle

5.2.6 External System Interfaces

Table 13 and Table 14 list the types of external interfaces expected to be used for system input and output feeds, respectively.

Table 13. External Interfaces of the System of Interest (Input Flows).

#	Input Flows	Description	Subsystem Destination(s)
1	PAL System	A set of transaction APIs to book ADA paratransit trips that include messages that support CTP functionality for booking, booking confirmation and status update messages. Additional messages may include cancellation requests. The APIs will be developed and provisioned by the external paratransit vendor.	CTP
2	NFTA Transit Vehicles	Data feeds using GTFS and GTFS RT (and maybe GTFS Flex) that describe scheduled and real time NFTA data. Additional data feeds for the Shuttle subsystem flex service are described in the Shuttle Trip Interface.	CTP
3	NFTA Elevator, Escalators Status	Data feed that provides information on NFTA station pathways including vertical paths (elevators, escalators). The data will be restricted to the stations in the project area. Additional real time status information will be provided as well. The format of the static pathways data has not yet been determined.	CTP
4	PROW & NITTEC Traffic Information	The data feeds provide: • Static information (see #4a) • Dynamic information (see #4b)	CTP
4a	PROW & NITTEC Traffic Information	The static network data includes right of way (ROW), public right of way (PROW) and parking capacity data feeds. The following data feeds are currently identified: • Road network or right of way includes rules and regulations will be downloaded from OpenStreetMap.	CTP

#	Input Flows	Description	Subsystem Destination(s)
		• Public right of way data includes features and conditions of sidewalk, crosswalk, curb cuts, and walking paths • Parking lot data (location, entrance/exit and accessible paths through the lot to the sidewalk or facility) • Facility entrances (including accessible entrances), pathways and vertical pathways (elevators/escalators/stairs) • Location of wayfinding assets -- indoor and outdoor • Location of traffic signal systems with pedestrian crossing functionality	
4b	PROW & NITTEC Traffic Information	The dynamic network data includes incidents on the road network in the project area, obstacles effecting traversal of PROW and parking fill data feeds. Broadcast information using standardized formats for traffic, incidents and work zone on right of way (arterials near in BNMC) • PROW real time obstacles (work zones, weather related conditions) • Parking lot occupancy • Incident and weather data (Several organizations in the area collect and disseminate situational awareness data through NITTEC). This data is based on the Traffic Management Data Dictionary (TMDD).	CTP
5	Fare System / Payment System	Link that brings up a specific page on a supported fare payment app already stored on a traveler's mobile device.	CTP
12	Traveler UI	The data flow provides transaction exchanges between the CTP and end users (travelers and caregivers). The UIs including exchanges using: • TIH (at bus stops, shelters, parking and other facility locations) • Call Center and IVR • Mobile app • Web browser The TIH, call center and web browser use a subset of the mobile app APIs. The APIs will include the following types of transactions: • Trip Planning • Selection of preferences and notifications • Selection of navigation processes and UI preferences	CTP

#	Input Flows	Description	Subsystem Destination(s)
		• Booking (PAL and Shuttle) processes • Actualization of notifications and wayfinding (indoor and outdoor) messaging • Requests for services (e.g., pedestrian signal request, shuttle and transit vehicles, facility wayfinding connections)	

Table 14. External Interfaces of the System of Interest (Output Flows).

#	Output Flow	Description	Source
10	Emergency Management: SDS Safety Interface	The data feed provides information about the SDS vehicles to emergency management center. The information enables the emergency management center (EMC) to monitor compliance with traffic regulations and passenger safety. In case of an incident involving a shuttle or a traveler onboard the shuttle, the SOC will communicate to EMC: (1) the location of the shuttle; (2) the nature of the incident; and (3) any additional information which would support Emergency Management in determining and applying the correct response.	Shuttle Subsystem
2	GTFS Flex and GTFS RT	The data feed provides real time updates on Shuttle services including location coverage, vehicle tracking and arrival times. The data will be published as open data for third party consumption.	Shuttle Subsystem

5.3 Stakeholders and Actors of the Proposed System

Table 15 describes the actors of the Travelers group for the proposed system, listing the changes in their roles and responsibilities.

Table 15. Proposed System Traveler Actors

Actor	Short Description	Roles and Responsibilities	Changes from Current System
Travelers	End-users of the complete trip platform and services provided by the concept	Travel using the services provided as part of the system	A new way to plan and execute trips using the CTP. New door to door service within the micro transit zone. Additional wayfinding to/from/within BNMC partner facilities and buildings

Table 16 provides the list of operator/partner users, as well as their roles/responsibilities.

Table 16. Proposed System Operator/Partner Actors.

Actor	Short Description	Role and Responsibilities	Changes from Current System
Shuttle Operations Center (NEW)	Systems of the public or private entity hired or assigned to operate the micro transit service defined in the concept	Operate the micro transit service including the SDS and HDS vehicles	This is a new actor
Complete Trip Platform Deployer (NEW)	Public or private entity hired or assigned to deploy or maintain the complete trip platform defined in the concept	Deploy and maintain the complete trip platform for the duration of the project.	This is a new actor
NFTA Paratransit Operations (PAL)	Systems (call center, web, and phone) and personnel used to support PAL operations	Service provider; Infrastructure owner and operator	New interface to CTP needs to be developed and maintained.
NFTA Operations	Systems and personnel involved in NFTA bus and rail operations. Also includes public and private traveler information systems currently in use at NFTA (Transit, Moovit, Agency website, phone) and associated personnel.	Services provider; Infrastructure owner and operator	Updated bus shelters. Updated process for collecting and monitoring outages. Maintenance of the SOI.
City of Buffalo Operations	Systems and personnel responsible for the streets, signals, sidewalks, bridges, traffic systems in the deployment area.	Infrastructure owner and operator; Planning & development	Support for intersection crossing system. Support writing the law enforcement interaction and emergency management plan.
NITTEC	Systems and personnel responsible for traffic operations collaboration in the Buffalo region.	Infrastructure owner and operator; Planning & development	Provide data to the complete trip platform and shuttle operations center about transportation network conditions
Regional Travel Demand Management (TDM) Services	Systems and personnel involved in travel demand management activities in the region including campus-wide initiative to create a more sustainable and active transportation system for employees on the Buffalo Niagara Medical Campus (BNMC TMA), the	Service provider; Outreach to end users	Supporting adoption of complete trip elements

Actor	Short Description	Role and Responsibilities	Changes from Current System
	regional Go Buffalo Niagara TMA, and statewide mobility management services (NSYDOT 511NY Rideshare).		
NYS Department of Motor Vehicles	Systems and personnel responsible for permitting self-driving shuttle operations.	Planning & development	Continue regulation of AV shuttle operations.
Emergency and Law Enforcement Entities	City, state and transit law enforcement and emergency systems and personnel responsible for monitoring emergency, safety of traffic and transit operations. Includes City of Buffalo, NFTA and NY State Police that may have jurisdiction in the system of interest.	Planning & development; Infrastructure owner & operator	Monitoring of shuttle operations and responding to emergencies. Lead writing the law enforcement interaction and emergency management plan.
BNMC Campus Entities	Partners included in the BNMC Transportation Management Association. Input from representatives from each of the partner agencies on travel needs for their employees and visitors. User group includes systems and personnel involved in partner's specific parking, access and traveler services. Five sub-groups are identified here around each for the partner agencies: • Roswell Park (RP) • VIA • Kaleida Health (KH) • University at Buffalo (UB) • Buffalo Hearing and Speech Center (BHSC)	Planning & Development; Employer; Outreach to end users	Installation of indoor beacons and touch models to support facility navigation through the complete trip platform.
Call Center Personnel (new)	Human actors involved in call center operations to support the phone-based access of the CTP or the community shuttle	Respond to calls regarding the CTP or the shuttle	New but can leverage existing call-center/customer support capabilities.
Shuttle Operations Center Personnel	Personnel working as part of the shuttle operations center	Operate and maintain the shuttle service.	New
Shuttle Driver	Drivers of the human driving shuttle	Drive the shuttle, pick-up and drop off passengers based on manifest.	New but can leverage existing staff capabilities.
Operator/Steward	Operators/stewards in the self-driving shuttle	Monitor and assist travelers in using the SDS. Be prepared to take over in case	New

Actor	Short Description	Role and Responsibilities	Changes from Current System
		of disengagement of the system.	

5.4 Support Environment

The Buffalo ITS4US system is designed as several loosely coupled subsystems that operate in their own operational environment. Generally, the support environment describes the systems, assets and capabilities needed to build, operate and maintain the Buffalo system. The integrated system relies on support services provided by data sharing, security framework, safety environment, and the power and communications network.

- **Data.** The CTP and Shuttle services are data driven, personalized to meet user needs. Currency, curation and quality are key factors in supporting the subsystems. Many existing data sources and collection tools are currently deployed in the region. These tools collect and provision static and dynamic data on the road network. Additional tools that collect, process and manage sidewalk, parking and indoor facility data will need to be acquired during the development stage. In addition, collecting and transmitting dynamic data including vertical conveyance, obstacles to walking and parking volumes are support functions that will provide rich information to support travelers. Tools to generate GTFS and GTFS real time are available by NYSDOT and other open-source toolsets.

- **Security.** A multi-layered security framework will be set up to protect the system (hardware and software), communications, and data from intrusion whether from vandalism, intrusion, cyber-attacks or to protect personally identifiable information (PII) of system users.

- **Safety Infrastructure / Assets.** Deployment of physical assets (e.g., digital signs, TIH, and vehicles) will need to conform to multiple safety policies and procedures existing across multiple agencies—for instance, safety and security installation and operation policies stablished by building owners.

- **Power and Communications Network.** Since many of the infrastructure components are outdoors, access to power and communications is a critical system to their operation and monitoring their operations.

5.5 Modes of Operations for Proposed System

The Modes of Operation for the Buffalo ITS4SU project are described in Table 17. The modes of operation for the system depend on the operations fidelity of each subsystem. To that end, the system modes of operations are described by degraded or failed dependencies among the subsystem components.

Table 17. Modes of Operations for the System

Mode	Definition
Operational (regular)	All interfaces and subsystems are operating normally.
Degraded with communications or data feeds from external systems, smart infrastructure or CTP	This mode occurs when interfaces are degraded or fail due to communications or data feed reduced availability, maintenance or other impacts. When the CTP subsystem identifies that data on which it depends is not verified, accurate or fails, the subsystem will revert to static information and alert end user or stakeholder about the degradation. The interfaces include real time tracking / ETA information from NFTA, PAL, Shuttle vehicles, smart infrastructure assets (facilities, traffic signals, etc.) or the services will revert to their independent subsystem modes of operations (e.g., pedestrian crossing requests will rely on manual actuation).
Degraded with communications or data feeds from smart infrastructure or CTP to Community Shuttle (particularly the SDS).	This mode occurs when external interfaces and services critical to operations or the SDS subsystem impact operations. When critical external information or services that are needed for safe operation of the SDS, the SDS will revert to a Mission Critical Event (Severity 1 or 2) mode of operations (see Section 5.2.2.4). HDS may replace the SDS if sufficient drivers and vehicles are available. When external information or services needed for a component of the subsystem, for example, scheduling or routing, the SDS will revert to a Minor Impact Event (Severity 3) mode of operations (see Section 5.2.2.4).
Degraded when community shuttle services dependent on other subsystems are in reduced availability or impacted.	This mode occurs when external interfaces and services which provide services to travelers (such as TIH, CTP) are degraded or fail due to communications or data feed reduced availability, maintenance or other impacts. When the community shuttle operations monitor that data on which it depends is not verified, accurate or fails, the component will revert to manual exchange of information. If manual processes are not timely or cannot provide the appropriate information, backup systems and communication channels are available to handle traveler communications. Manual processes will be needed to book, route and dispatch customers.
Failure	Failure mode operates as a mission critical impact. Information provision, communications and services between systems will be manually implemented. If no backup or redundant service if available, the operations will be suspended temporarily.

5.6 Operational Policies and Constraints

The following are some operational policies and constraints identified for the proposed system. We understand that this is an initial list based on our understanding of the proposed system at the time, and therefore these may change during the design and testing phase of the project.

- Position accuracy as there may not be GPS service available in buildings. To mitigate this risk, the proposed concept includes indoor beacons that can provide some localization functions.
- Latency and format of sharing of information between various sources is critical and a data policy needs to be established between various system owners.
- Maintenance policies and requirements for smart infrastructure elements need to be established.
- Integration of smart infrastructure depends on access to power and communications networks. The positioning of the assets may be driven by access to these utilities.
- Service plans for the shuttle service are to be determined including the desired time and location of operation. Trips' origins and destinations will have to be within the service area of the micro-transit subsystem.
- Policies around navigating indoor pathways need to address the security protocols of partner agencies.
- Increased preferences in travel characteristics could limit trip alternatives. In addition, some trip preferences may not be consistent or compatible with mobile handsets and operating systems.
- Any delays in ongoing and planned projects, detailed in 3.2.1.6, could impact the opportunity to leverage their improvements for this deployment project.
- The proposed system will be limited to the budget, manpower and hours of operation established by the Buffalo ITS4US partners and lead for Phase 2.
- The CTP in the proposed concept relies on a variety of existing and publicly available open-source software, interfaces, features and application modules. These features and modules will be re-used or repurposed without "re-inventing the wheel." The Open Trip Planner (OTP) is continuously being improved, and additional functionality and standard feed specifications and interfaces are deployed on an ongoing basis. The specifications ingested by the OTP and external interfaces consumed by third party systems will constrain the system in order to use the services and methods deployed in the system.
- The system will rely on available standards for providing data feeds to the data-driven subsystem. These standards include:
    - Traffic Management Data Dictionary (TMDD).
    - GTFS family of standards including GTFS, GTFS real time, GTFS-Flex and perhaps GOFS and GTFS-Pathways.
    - OpenStreetMaps to support the Open Trip Planner (OTP).

6 Operational Scenarios

This section presents the selected use cases (UC) for the proposed system. Each use case provides a brief description of the interaction between the actors and the system under the depicted scenario, a list of the goals, constraints and applicable geographical scope. Each use case also identifies the actors involved and describes the main method of operations, as well as any alternatives. Pre- and post-conditions for the use-case are also identified along with the information requirements and the user needs associated with the use case.

6.1 Complete Trip Use Case Framework

6.1.1 Complete Trip Framework Description

The complete trip framework is composed of trip segments and transition points needed by a traveler to prepare, begin, navigation, and transition between modes and indoor and outdoor spaces. In the Buffalo Complete Trip project, the traveler has multiple options for mode selection including walking, crossing intersections, fixed route bus (NFTA), fixed route light rail (NFTA), community shuttle, and paratransit service (NFTA PAL). Although other modes are available including driving, transportation network companies (TNC), bike and shared use modes, those will not be emphasized during the project. As depicted in Figure 19, the complete trip process is ordered by 10 use cases that describe a traveler's interaction with the CTP (i.e., numbers in diagram correspond to use case identifiers). In addition, a second set of use cases describes the traveler's interaction with the Community Shuttle services including vehicle services and options. Finally, the traveler will interact with the traffic signal system to implement hands-free pedestrian crossing. The pedestrian signal crossing use case is enabled through CTP message and communications.

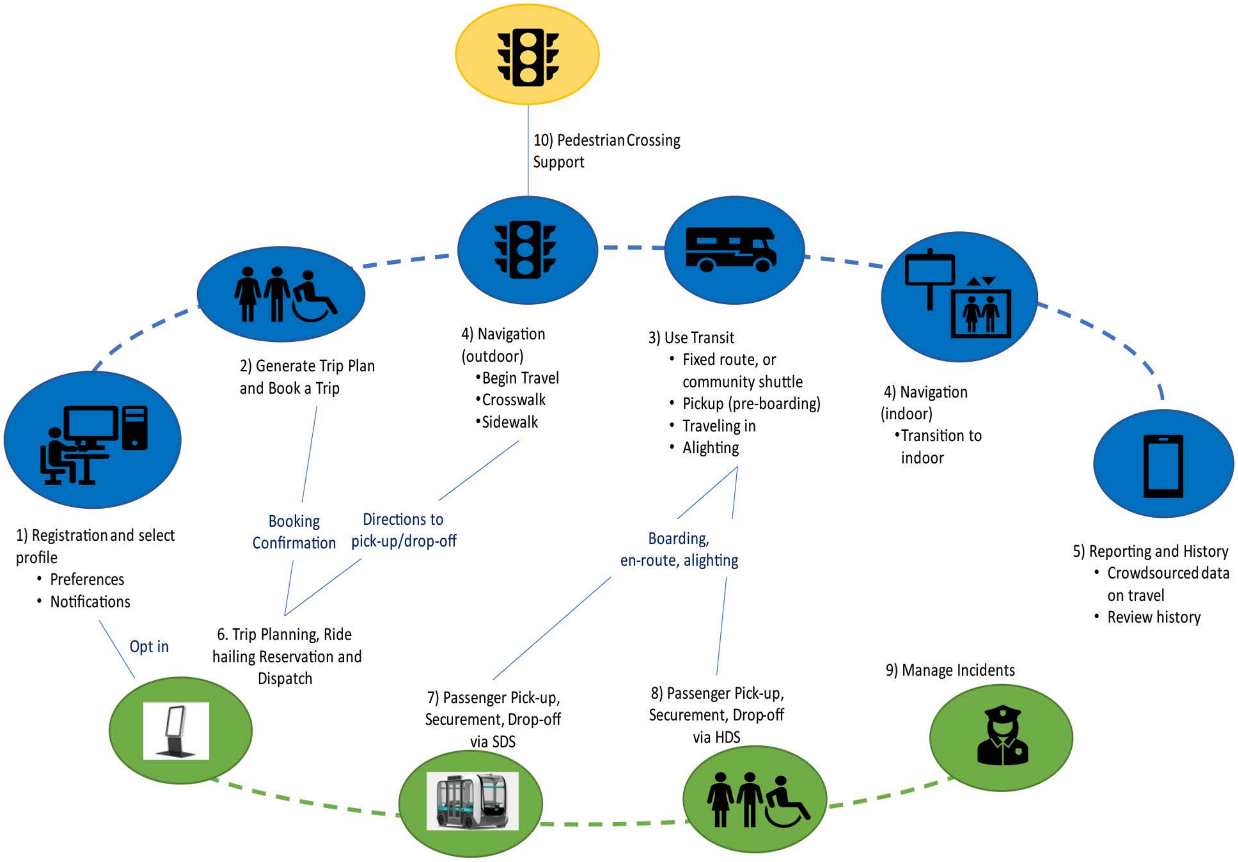


Figure 19. Complete Trip Travel Scenario Framework.
Source: Buffalo, NY ITS4US

6.1.2 Use Case Summaries

As shown in Figure 19, the complete trip framework corresponds to ten use cases that are described in Sections 6.2, 6.3 and 6.4. The use cases include:

- User Focused (Section 6.2)
  - UC 1: Register Profile and Preferences
  - UC 2: Generate Trip Plan and Book a Trip
  - UC 3: Public Transport Services
  - UC 4: Navigation
  - UC 5: Reporting and History
- Community Shuttle Operations Use Cases (Section 6.3)
  - UC 6: Ride-hailing Reservation and Dispatch

    - UC 7: Passenger Pick-up, Securement and Drop-off via the SDS
    - UC 8: Passenger Pick-up, Securement and Drop-off via the HDS
    - UC 9: Manage Incidents
- Smart Infrastructure Use Case (Section 6.4)
    - UC 10: Intersection Pedestrian Crossing (PedX) Request

6.1.3 Traveler Scenarios

Six scenarios describe how different traveler groups will interact with the Buffalo Complete Trip System. These scenarios depict travelers with different needs including preferences for modes, user interface and communications channels, notification types, and other services. Each scenario includes a user persona, profile of their preferences, and a narrative of their travel experience. The scenarios depict the following personas:

- Scenario #1 Pauline Jones – Older adult, low vision, low income
- Scenario #2 Leon Williams – Older adult, wheelchair user, low income
- Scenario #3 Jessica Benz– Deaf, healthcare IT worker
- Scenario # 4 Amelia Martinez – Caregiver, limited English proficiency
- Scenario #5 George Franklin – Blind and diabetic
- Scenario #6 Lisa Michaels – Power wheelchair user, volunteer at Oishei Children's Hospital

6.1.3.1 Scenario #1 Pauline Jones – Older adult, low vision, low income

Pauline Jones is 82 and lives by herself in a small ranch house in the Fruit Belt neighborhood. She is fiercely independent but over the past ten years she has experienced macular degeneration that has significantly reduced her central vision, depth perception, and contrast sensitivity impacting her ability to read, recognize faces or signs, and use digital devices. As a result of her age, Pauline also has difficulty walking for long distances and has moderate hearing loss. She no longer drives. Her children and grandchildren do not live nearby and have busy work and family schedules and often cannot assist Pauline with her transportation. She has started to use a white cane when she leaves her property to reduce the likelihood of tripping while on the sidewalk. Pauline is going to visit VIA for the first time to receive "Vision Rehabilitation Services" where she plans to learn some ways to more effectively perform activities of daily living such as identifying her medications and preparing her meals. She has not used the Complete Trip Platform app (CTP) before. She does not use the internet and does not own a smart phone.

Pauline Jones Profile Preferences

Accessibility Needs:
- Accessible pathways
- Most efficient route / minimum transit modes
- Preferred drop-off point/ Facility entrance: Main accessible entrance

Communication and Information Needs:
- Preferred communication method: Call to home phone
- Frequency/Type of information needed:
  - Transit arrival time
    - Notification time: 10 minutes before arrival
  - Trip delays

What is Pauline's round-trip traveling experience throughout the travel chain?

Plan Trip: In preparing to travel to VIA, Pauline calls VIA for information on transportation options to pick her up/take her to the Main/Best VIA location. The receptionist at VIA suggests that, because Pauline does not have access to a smart phone or the internet and she lives the in the Fruit Belt community, she should take the Community Shuttle. She can set up an on-demand trip by calling the phone number for the Community Shuttle (driven by a human operator) to book a ride.

Pauline calls the number and talks to the agent. The agent opens a form that is available from the CTP to reserve the shuttle. The agent reads the form to Pauline asking for contact information including address and phone number, preferences for services and the provision of information, when she wants to book her trip (origin and destination), and if she would like to save this information to an account. When the agent confirms the information, he saves the information and sends the request through the CTP to the Shuttle Operations Center (SOC) for booking. The agent confirms the information in the reservation including pickup time and place (1/2 block from her home in 30 minutes) and drop off time/place (VIA in about an hour). Finally, the agent asks Pauline if she would like a call back when the shuttle is within 10 minutes, and she agrees. She is told that she needs to wait at the curb for pickup.

(In responding to the reservation request, the SOC checks for a pickup location that is fully accessible and close to Pauline's home, and the location of a shuttle that will pass by her street.)

Begin Trip: 10 minutes before her trip, Pauline receives an automated call on her home phone that the shuttle is on its way, her driver's name is George (an NFTA driver), and the vehicle number is 1234. The call confirms the pickup stop and side of the street. Pauline makes her way out of the house, and proceeds to the pickup point. Because of the sidewalk conditions and curb heights, she walks very carefully and slowly. By the time she arrives at the stop, the shuttle is waiting for her.

Public Transit Service: When she reaches the shuttle stop, the shuttle is making an announcement over its external speaker that vehicle #1234 for Pauline has arrived. Pauline boards the shuttle and sits down at the first available seat she notices. As Pauline is the only rider, the vehicle announces that she should secure her seat belt and the next destination is

VIA and they will arrive in 11 minutes. Once secure, the vehicle begins to move and arrives at the shuttle drop off point within half a block from the VIA entrance.

Note: Pauline needs to ask directions of the vehicle operator to find VIA, and once she is inside Pauline asks for directions to her destination. An intern escorts her to her appointment.

Return trip home: The receptionist at VIA lets Pauline call the shuttle services to book her return trip. Using her existing account registration, the agent generates the trip in seconds. Pauline also saves the round-trip plans (calls them VIA) for her next time to VIA. The return trip is booked for 30 minutes at the same place she was dropped off. She lets the agent know that she will wait outside because she does not have a cell phone or access to a phone, so no call backs are necessary. The return trip is just as convenient for her as her first trip.

6.1.3.2 Scenario #2 Leon Williams – Older adult, wheelchair user, low income

Leon Williams is 72 and lives with his wife, Laura, in Masten Park. Both are retired and live on a modest fixed income. Leon had a stroke in 2015. He is in reasonably good health, aside from the loss of function to the right side of his body. Leon uses a manual wheelchair for his mobility, but he is unable to travel independently; he needs assistance pushing his wheelchair. He can speak clearly when he is not tired. His wife, Laura, assists him with many of his activities around the house, but she does not drive. Since his stroke, Leon regularly visits his primary care physician for routine check-ups and follow-ups related to his circulatory health. Laura (or another caregiver) accompanies him on these visits. His primary care physician is in Buffalo General Medical Center's Primary Care Center (PCC) located on 100 High Street. The Williams have internet access. Leon can use his old home computer reasonably well and uses a non-smart cell phone for calls only because he can use his left hand (previously his non-dominant side) with proficiency. He regularly uses the Complete Trip Platform via his computer to arrange his trip to and from Buffalo General Medical Center.

Leon Williams Profile Preferences

Alternative User: Laura Williams

Accessibility Needs:

- Accessible pathways
- Most efficient route / minimum transit modes
- Accessible transportation
  - Mobility Device: Manual wheelchair
  - Securement Points: 4
- Preferred drop-off point/ Facility entrance: Main Accessible Entrance

Communication and Information Needs:

- Preferred communication method: Call to mobile phone
- Secondary communication method: Email
- Frequency/Type of information needed:
  - Transit arrival time
    - Notification Time: 10 minutes before arrival
  - Trip delays

What is Leon's round-trip traveling experience throughout the travel chain?

Plan Trip: Since Leon is a frequent user of the Complete Trip Platform, he has the website bookmarked on his computer. He logs into the website and with his preferences and eligibility for PAL already loaded (e.g., need for wheelchair securement, saved trips, caregiver). Leon opens CTP and pulls down his saved trips for a PAL trip to the PCC. The saved trip has his origin / destination and preferred mode; he is also asked if he wants to change any of his preferences for the trip – arrival for the first and return travel via a telephone call to his mobile phone or caregiver support (his default includes his wife as his caretaker), for example. He adds the trip time and return trip information into the CTP trip request form. Since it is a nice day, Laura suggests they go for a 'walk' in the area after he is done with his appointment and before returning home. Leon therefore changes the return trip pickup location to the Oishei Children's Hospital entrance (across from High and Ellicott streets) by moving his cursor to the new pickup location and tapping the location. He is sent a request to confirm the return pickup location, which he does, and then he submits the completed information.

[The CTP connects to PAL Direct and sends his request to PAL which checks for his trip eligibility and availability of service given his trip needs before it returns a confirmation receipt.]

Leon receives a confirmation receipt on his trip reservations on his CTP account, and he also receives an email confirmation at the email account on file with CTP. The confirmation includes a standard receipt which includes confirmation number and details of his pickup / drop off, return trip time and location, accessibility needs, and number of passengers. The email has a map of the pickup and drop off locations and times of travel and return trips which Leon prints out to take with him.

Begin Trip: As requested, Leon receives an auto generated call ten minutes before arrival of the PAL vehicle to pick him up outside his home. The call includes the trip confirmation number, estimated time of arrival of his vehicle, number of expected passengers, and pickup location. He is asked to confirm verification, which he does by saying "yes" into the phone.

Public Transit Service: With the help of Laura, he navigates to the pickup location where he is to meet the paratransit vehicle. (Note: PAL operations are out of scope of the project.)

Navigation: Since Leon doesn't use a smart phone, he is unable to take advantage of the smart signage system to help him navigate inside. Fortunately, over time, he has learned his way around the hospital and doesn't require additional wayfinding support.

Return trip: After the walk, Leon and Laura travel to their new pickup stop at the Oishei Children's Hospital. To do this they need to cross the intersection on High Street, across Ellicott. At the intersection, Leon overhears a pedestrian showing their CTP app to their friend about the feature he activated to request pedestrian crossing. Because Leon is a frequent user of the CTP, he asks about the feature. The person mentioned that the app does all the work. He set up his trip plan, set up the trigger to request a walk signal when he is near the signal, and the app does all the work, "pushing" the button to cross Ellicott Street, providing him with a confirmation that the request was sent, and then sending him information about how soon until the signal will change. Then once the signal is green, how long he has to cross the street. Leon mentions to Laura, that the feature is so novel, this might be a reason to buy a smarter phone!

After the pedestrian signal changes, Leon and Laura cross the street and make their way to the pickup stop just as he receives the ETA call about the vehicle ID and location. He confirms the call and waits for the pickup.

6.1.3.3 Scenario #3 Jessica Benz– Deaf, healthcare IT worker

Jessica Benz (she/her) is 24 years old and lives in Buffalo's University Heights District with a roommate. She received her B.S. in computer science from the University at Buffalo in 2018 and is currently employed as an IT Systems Analyst for the Roswell Park Cancer Institute. She uses the NFTA Metro/light rail to commute to work, boarding at the University Station and exiting at the Allen-Medical Campus Station. Sometimes she is nervous about commuting home at night after a long day, particularly when she is required to wait for the metro. Jessica has been deaf since birth. She is highly proficient in ASL and can read lips. She is exploring new technologies and software phone apps that will support her lifestyle preferences, including her travel preferences.

Jessica Benz's Profile Preferences

Accessibility Needs:

- Most efficient route / minimum transit modes
- Text-based notifications

Communication and Information Needs:

- Preferred communication method: Text
- Type of Information Needed:
  - Trip delays
  - Elevator/escalator outages
  - Maximum walking time
  - Name of transit stops
  - Estimated time of arrival at destination
  - Transit vehicle / shuttle arrival time
    - Automatic notification 10 minutes before arrival

What is Jessica's round-trip traveling experience throughout the travel chain?

Plan trip: After learning about the Complete Trip App through a Roswell employee newsletter, Jessica downloads the app on her phone and decides to try it out for her trip home from work tomorrow. She sets up an account via her home computer, setting her contact information, trip preferences, navigation services, and notification and user interface preferences. She generates a stored trip to and from work and sets notifications to alert her when her train is delayed. She plans to use the light rail as she typically does to get to work. She has a smart watch that includes a vibration alert that she set up to be triggered when a CTP notification is received.

Begin Trip: As Jessica leaves, she opens the CTP app on her phone, logs in and pulls out the stored trip plan which she named Daily Commute. She taps the BEGIN TRIP NOW button (no changes to the saved trip plan), which causes the trip plan to download to her phone, and provide information on her navigation, wayfinding and connections. A few general notifications appear about light rail delays, elevator/escalator outages, and the building where she works. On her app's trip plan, she sees a schedule panel with a list of three or four next train. She sees that there is a train in 2 minutes and in 10 minutes. If she hurries, she might make the trip in 10 minutes. As is her usual route, Jessica walks the two blocks from her apartment to the University station and uses her monthly pass to board the NFTA light rail heading south.

Public Transit Service: While riding the light rail, Jessica reads the signs at each stop as well as the real-time information on the train to know where she is along the route and when her stop is approaching. She set the trip plan to show her the ETA to her destination station. She cannot receive real time information in the station, but the CTP shows her the stops and estimates of the time until arrival at her destination station based on the schedule information.

Navigation: Jessica exits the light rail at the Allen-Medical Campus station and takes the escalator up to the ground level. She exits the station and makes a left onto Main Street and then another left onto Carlton. She arrives at the main entrance to Roswell 4 minutes later.

Return trip: By the time she leaves work it is dark, and Jessica is concerned about walking to the light rail station. Instead, she decides to take the Fixed Route AV Shuttle which she understands stops about half a block from where she works, and it will take her to the LRT. She does not quite know where the stop is, or when the shuttle is expected. So, she reviews the CTP website for details. She locates the stop (right at the entrance to her building) and it travels to the parking facility before it stops at the LRT station. She is asked to generate a trip plan from the shuttle stop, so she generates a trip plan.

The app also provides her with information about connecting her app to the communication channel onboard the vehicle so that she can acquire messages (voice to text) on her phone that are announced in or near the vehicle. She sets up the communication mode and a notification that alerts for several predefined times before its arrival at that stop and saves the trip plan and its preferences under the nickname of “Too late” trip. The app also provides her with detailed instructions about the rules for riding in the shuttle. On her way out, Jessica activates her CTP and loads the “Too late” trip. The screen shows her that she has 15 minutes until the shuttle arrives (it is running slightly late), and it currently has three passengers.

Five minutes later, Jessica feels a vibration from her smart watch (which is linked to her phone) that she just received a notification. She looks at her watch, which shows the 10-minute alert to the arrival of her shuttle and it now has 2 passengers. She is getting cold, and so she pulls up the CTP app and a map of the AV Shuttle shows up on the screen with its current position. She looks down the block and sees its headlights, so she knows that it is close. When it arrives, there are only two passengers. When the vehicle stops, her mobile app alerts her that she is connected to the AV user information channel, and she sees that this is the right vehicle to take to the NFTA station. The message also reminds her to press the button on the left side of the door. As she boards, the vehicle provides her with instructions about seating and destination via a sign in the shuttle and a notification on her phone. As the vehicle closes its doors and travels to the next stop, she is alerted to the next stop information. There is also a sign in the vehicle with the same information that she is reading on her phone. The vehicle also identifies the stop request button. When the vehicle leaves the stop before her stop, she presses the button on the vehicle she receives an alert on her phone that a stop was requested.

At her stop, several people are alighting from the vehicle. They all take their turn to disembark. The vehicle detects that there are people without their seat belts, so the vehicle does not shut the door until all passengers have either alighted the vehicle or have their securement in place.

Jessica then hurries down to the NFTA rail platform to catch her LRT home.

6.1.3.4 Scenario # 4 Amelia Martinez – Caregiver, limited English proficiency

Amelia Martinez is 62 years old and lives in the Fruit Belt neighborhood with her son, daughter-in-law and two grandchildren, Julia, age 14, and Marco age 12. She is in very good health for her age. Her son and daughter-in-law work full-time at the nearby BNMC. The only family car is left at the house during the day so that Amelia can run family errands. Marco has Down Syndrome, limited independence in his daily living skills, and is severely obese. Marco also has loose joints that have led to hip problems as a result of his disability. Due to several operations on his hip throughout his childhood, he uses a rollator and cannot walk long distances. Marco requires a large degree of supervision and assistance, especially when walking. When they are not in school, Amelia oversees almost all of her grandchildren's afternoon activities, including taking Marco to doctors' appointments. Although Amelia only has a basic cell phone, Julia has a smart phone, which is part of her parents' family plan, with unlimited data and the ability to connect to Wi-Fi. Since Julia often accompanies her brother and grandmother, she has the CTP app downloaded on her mobile phone. While Julia speaks English fluently, Amelia is most comfortable communicating in Spanish but can communicate basic ideas in English when needed. Her daughter-in-law (Marco's mother) is bi-lingual and usually sets up the appointments for her son ahead of time. Amelia and Marco frequently visit the Down Syndrome Center at Buffalo's Oishei Children's Hospital. Sometimes (but not always) Julia comes along for these trips. Amelia parks at BNMC's Central Garage.

Marco Martinez Trip to BNMC Profile Preferences

Alternative User(s): Amelia Martinez, Marco's Mother

Accessibility Needs:

- Accessible pathways
- Most efficient route / minimum transit modes
- Preferred drop-off point/ Facility entrance: Main Accessible Entrance
- Accessible vehicle (ramp or lift)

Communication and Information Needs:

- Preferred communication method: Text
- Secondary preferred communication method: Call to Amelia's phone (if indicated in booking)
  - Secondary preferred communication method language: Spanish
- Frequency/Type of Information Needed:
  - Transit arrival time
    - Notification Time: 5 minutes before arrival
  - Trip delays

What is Amelia's round-trip traveling experience throughout the travel chain?

Plan Trip: At her last visit with Marco's doctor, Amelia heard that there is a fixed route AV shuttle and an on-demand shuttle service around/in the BNMC that is free for use to transport her and Marco to the Children's hospital. She received a flyer in Spanish and English about how to use the shuttles, and the best one to accommodate her family from the garage to Oishei Children's Hospital. The flyer discussed how to use the Transportation Information Hub (TIH) or the CTP app to hail the on-demand shuttle. So, when she next takes Marco to the doctor's office, she decides that she might try it out.

Begin Trip: Amelia, Julia and Marco get into their car and drive to the BNMC. They park the car in the central parking garage located on High Street. Before she leaves the garage with the two kids, they stop at the TIH located at the garage exit to request a shuttle to the Oishei Children's Hospital main entrance. The TIH shows a map and a trip plan form. There is also an icon on the top of the screen with an American Flag next to the word English. Julia is familiar with web browsers and sees that they might be able to translate the screen to Spanish if she taps on the down carrot and pulls up the Spanish flag with the word "Spanish". Amelia taps on the "Spanish" and the form and map text are translated to Spanish. The form is populated with her current location and includes a pulldown list of destinations on the campus. She selects the Oishei Children's Hospital and inserts that there are three passengers. She includes a nickname for herself and the two children so that shuttle knows who will be picked up. The form also asks if any of the passengers need special services, and their age (e.g., for special seating). Amelia submits the requested trip plan, and the TIH shows her community shuttle, walking, and fixed route shuttle options (in order of best option). Given her preferences, the best option is the community shuttle. Amelia selects the community shuttle booking option and is asked for basic information (e.g., her first name) and confirmation of the number of passengers.

Amelia submits the request, the screen tells her the confirmation is pending, and please wait. Within 30 seconds the screen displays a confirmation that she and her grandchildren will be picked up in 10 minutes at the designated central garage pickup location. The shuttle number is 1234, the driver/steward is George. Included are a set of instructions for riding the operator driven shuttle.

Julia sees that there is an app with turn-by-turn directions around the BNMC, so she decides that she'll download the app and set it up while she waits for Marco's doctor visit.

Public Transit Vehicle: As the shuttle arrives, an announcement is made in Spanish and English for the Martinez family to board. The driver confirms their identity, lowers the ramp for Marco to board and helps the family find seats. The operator also tells them they are third stop and he'll announce their stop when they arrive. At their stop, right in front of the hospital reception area, the operator lowers the ramp so they can alight the vehicle.

Navigation (Indoor): Amelia knows how to get to Marco's doctor's office, but he needs to get to a laboratory in the hospital, so they go to the indoor TIH unit in the lobby (which also has a Spanish language translation function). Amelia is now a pro at finding information. This terminal has indoor directions and elevator / escalator status. She selects the indoor trip plan feature form. It is prepopulated with her current location, so she pulls down a list of the offices and centers in the building and selects the lab she is looking for. She also inserts that she needs an elevator. The indoor trip plan is created, and the map on the screen shows which elevator bank to use and the floor where the office is located. Julia wants to play with the CTP app, so she opens her app account, and downloads the trip plan generated by the TIH to her phone by logging into her account on the TIH. This allows the trip plan to be loaded into her account and available through her mobile app. The indoor navigation plan is enabled by linking her phone to the indoor navigation beacons (through an existing communications technology supported on her phone). She connects to the beacons by her phone and receives turn directions as they travel through the corridors. The CTP app also sends directions to the correct elevator bank, through the bridge to the next building, and then to the lab facilities.

Return trip: After the lab, the trio finds an exit to the street, but no TIH is available. Julia pulls out her phone, but Amelia asks her granddaughter if she can try. Julia turns the language on the app to Spanish and hands the phone to Amelia. Amelia requests the shuttle through the app and receives notifications that the shuttle will arrive in 30 minutes, 5 minutes, and then it flashes "arriving". Slowly they make their way to the pickup point. As they are walking another message arrives that the vehicle has arrived and will wait for them for 5 minutes. As expected, the operator on-demand shuttle is at the pickup location and helps them board the vehicle to take them to the Central Garage. When she arrives at the garage, the CTP app provides Amelia with turn-by-turn directions to the bank of elevators they will use to reach their car. All of these notifications are in Spanish – and Amelia is impressed!

6.1.3.5 Scenario #5: George Franklin – Blind, diabetic

George is a 35-year-old who lost his vision when he was 8 years old. Since George has been blind for most of his life, he has gone through extensive Orientation and Mobility Training (O&M Training) and has spent most of his life navigating independently throughout his Masten Park community. George is very tech-savvy and uses an Android smartphone. George also uses a guide dog, a yellow lab named Frank. George has diabetes, which is why he has quarterly appointments at the BNMC General Medical Center. George typically walks from his home in Masten Park to his medical appointments at the Buffalo General Medical Center via Northampton to Main Street and then back to East North Street. However, with the construction underway on Main Street, George will be looking for another route to his medical appointment.

George Franklin's Profile Preferences

Accessibility Needs:

- Accessible pathways
- Most efficient route / minimum transit modes
- Preferred Drop-Off Point/ Facility Entrance: Main Accessible Entrance

Communication and Information Needs:

- Preferred Communication Method: Text
- Second Preferred Communication Method: Call to Mobile Phone
- Frequency/Type of Information Needed:
  - Transit arrival time
    - Notification Time: 10 minutes before arrival
  - Trip delays
- Turn-by-turn navigation (indoor and outdoor)
  - Audible
    - 15 feet ahead of turn
    - At time of turn

    - Haptic (vibration)
        - At time of turn
- **Intersection Communications (signaled and non-signaled)**
    - Audible
    - Notify when approaching any intersection
    - Signaled - Notify of walking time to cross intersection
    - Obstacles in path of travel
        - Weather related
        - Construction

What is George's traveling experience throughout the travel chain to his medical appointment?

Plan Trip: When George last visited the medical center, he met with the Orientation and Mobility Training coordinator to work out an alternative route to walk to his medical appointments. The coordinator mentioned the new CTP app that finds the safest route for people with low vision and provides turn-by-turn directions using voice or haptic alerts. In finding the safest route, the app locates trip segments that traverses signalized intersections with pedestrian crosswalks, particularly ones that may be activated by a mobile app. The coordinator also lets George know that the BGMC also implemented a smart sign system that enables indoor navigation using the same app, includes call in support services to a caregiver or call center and other features that will help George navigate independently to his destinations. The coordinator works with George to set up his CTP profile, setting up his preferences for notifications, support services, automated detours and controls, orientation, saved trips, and more.

Begin Trip: So, the next time George sets out to visit his doctor, George talks to his phone –

- "*Google*, open CTP app"
- "*CTP*, start *Medical Center* trip plan"

When starting the trip plan, the CTP app initiates a notification that triggers a vibration (haptic alert) on his e-watch, and begins with a voice message that starts: "Main Street is under construction, do you want an alternative trip plan?"

George responds – "yes" to his smart watch

CTP App – "New route calculating…. recommended reroute: travel on Northampton Ellicott (through 4 intersections, about 100 feet); turn left on Ellicott Street, travel half mile (through 5 intersections) to High Street. Left on high to BGMC entrance. Trip plan includes 9 crosswalks (5 include pedestrian crosswalks), average sidewalk score of 4 (out of ten, where 10 is best). Travel time is 20 minutes. Say yes if you accept this trip plan."

George responds – "yes."

Public Transit Vehicle: None included in this operational scenario.

Navigation: George begins walking in the direction with Frank alongside. Just before he gets to the intersection of Northampton and Ellicott, the app says: "Masten street, cross intersection 15 feet ahead. Signal ahead with pedestrian crossing." At Masten, he receives a vibration to cross intersection. George positions Frank to wait until walk signal alerts him to cross street.

The app then alerts him to rough and narrow sidewalk conditions between Masten and Michigan.

As George approaches Michigan, the app says: "Michigan and Northampton intersection ahead, cross intersection 15 feet ahead. Signal ahead with pedestrian crossing." At Michigan, he receives a vibration that he needs to cross the street.

The app lets him know that the sidewalk conditions are improved, but still narrow between Michigan and Ellicott.

As George approaches Ellicott, the app says: "Ellicott and Northampton intersection ahead, turn left 15 feet ahead." At Ellicott, he receives a vibration that he needs to turn left.

As George approaches Ellicott, the app says: "Ellicott and Southampton intersection ahead, cross intersection, no signal. Be careful in crossing the street." At Southampton, he receives a vibration that he needs to cross the intersection.

The app lets him know that the sidewalk is narrow (only wide enough for himself, but not Frank).

As George approaches Ellicott, the app says: "Ellicott and Cory Place intersection ahead, cross intersection, no signal. Be careful in crossing the street." At Cory Place, he receives a vibration that he needs to cross the intersection.

The app lets him know that the sidewalk is narrow and there is a fence on his left.

As George approaches Ellicott, the app says: "Dodge and Ellicott intersection ahead, cross intersection, no signal. Be careful in crossing the street." At Dodge, he receives a vibration that he needs to cross the intersection.

The app lets him know that the sidewalk is not flat (it slants), to stay to the left.

As George approaches Michigan, the app says: "Best and Ellicott intersection ahead, cross intersection 15 feet ahead. Signal ahead with pedestrian crossing." At Best, he receives a vibration that he needs to cross the street.

As George approaches a major driveway, the app says: "Approaching driveway of parking garage 15 feet ahead". As he nears the driveway, he receives a vibration that he will be crossing the driveway.

As he nears High Street, the app says: "Ellicott and High intersection ahead, turn left 15 feet ahead." At High Street, he receives a vibration that he needs to turn left.

The app lets him know that obstructions are on the right, stay to the left. Entrance to destination is 25 feet ahead. At 15 feet ahead, the app informs him that he will need to turn left to the entrance and that the sidewalk curves to the left.

At this point, George loses his GPS signal because he is under the canopy of the entrance. As he approaches, because he set up his smart phone to connect to the Center's Smart Sign system at the entrance, the app confirms that he is now connected to the Medical Center Smart Signs.

The Smart Signs provide George with orientation messages as he passes a sign location – accessible entrance is on the left when facing the building. Automated door button is on the left of the door.

As George enters the building, the orientation message presents him with the directions to different office, elevators, escalators, other information, and support services. Since he knows his way through the building, he decides to turn off the orientation messages and just keep the alerts and notifications. As he walks to his doctor's office, he receives a notification that the floor is slippery ahead, watch for warning cone on the floor.

When he arrives at his destination, the doctor's office, he confirms that he has arrives and shuts off the CTP app.

Return Trip: Not included.

6.1.3.6 Scenario #6: Lisa Michaels – Power wheelchair user, volunteer at Oishei Children's Hospital

Lisa is 20 years old, attends the University of Buffalo, and volunteers at the Oishei Children's Hospital. Lisa is a complete paraplegic and uses a power wheelchair for mobility. Lisa lives in the Fruit Belt neighborhood and is an active member of her community. As a young student, Lisa frequently uses technology for both school and social activities – primarily using Apple products like her Mac for school and her iPhone for everything else. Lisa's family cannot afford their own accessible vehicle, so Lisa relies on PAL for all of her transit needs. Lisa must reserve PAL for her daily class schedule, but sometimes she is asked to fill in for volunteer efforts, and does not have time to schedule PAL services if she is asked to volunteer after 8 p.m. Now with the CTP app and the on-demand PAL services in the BNMC and Fruit Belt community, Lisa can volunteer even on the same day. She started using the app as part of the initial pilot, and now uses it all the time.

Lisa Michael's Profile Preferences

Accessibility Needs:

- Accessible pathways
- Most efficient route / minimum transit modes
- Accessible transportation needs
  - Mobility Device: Power Wheelchair
  - Securement Points: 4
- Preferred Drop-Off Point/ Facility Entrance: Main Accessible Entrance

Communication and Information Needs:

- Preferred Communication Method: Text
- Secondary Communication Method: Call to Mobile Phone
- Frequency/Type of Information Needed:
  - Audible notifications
  - Transit arrival time
    - Notification Time: 10 minutes before arrival

- Trip delays
- Elevator outages
- Obstacles in path of travel
  - Weather related
  - Construction
  - Closed entrances
- Other Information Needed:
  - Types of Transit Stops (shelter vs. no shelter)

What is Lisa's traveling experience throughout travel chain to her volunteer services?

Plan Trip: After receiving a call from volunteer services asking if she could fill in from 2 to 5 pm today, Lisa readily agrees. She has a saved trip on her app to request an on-demand PAL vehicle. Her experience with hailing the vehicle requires that she request the trip at least 30 minutes in advance. At 45 minutes before her service begins, she activates the app –

Lisa: "SIRI, open CTP app, open volunteer trip plan, activate plan to leave now"

The saved trip includes a trip from her house in Fruit Belt to the volunteer office in the Children's Hospital. It includes the PAL pickup point (at the curb by her house), to the front door of Oishei, and then the volunteer office on the 2nd floor.

The app sends the request to the on-demand PAL reservation site and 30 seconds later receives a confirmation that her vehicle will pick her up in 25 minutes at her normal pick-up location. Her driver's name is Marcie, her motorized wheelchair with 4 securement points will be accommodated, and her drop off point is at Oishei.

Begin Trip: Fifteen minutes later, Lisa receives a vibration indicating that her vehicle will arrive in ten minutes. As she makes her way out the door, she gets to the pickup point within four minutes of its arrival.

Public Transit Vehicle: The driver lowers the ramp, and Lisa motors onto the van. With the help of the driver, Lisa secures her wheelchair. When Lisa arrives at Oishei, the driver helps her with releasing the securement and lowers the ramp so Lisa can disembark from the vehicle.

Navigation: As Lisa enters the Hospital, she receives a text that pops up on her smart phone, which is mounted on her wheelchair. The notification alerts her to the east elevator bank, since several of the elevators on the west side are under repair. She heads right, instead of her normal left turn she usually makes when she enters the building.

Return Trip: As Lisa gets ready to leave, she activates her CTP app to book a return PAL on-demand reservation. The reservations message returns with a pickup time of over hour duration. Lisa agrees to the reservation and requests updates on the status when the vehicle is on its way. Lisa then decides to call her "support services" (which is the Call Center) to see if they can accommodate her trip using another mode.

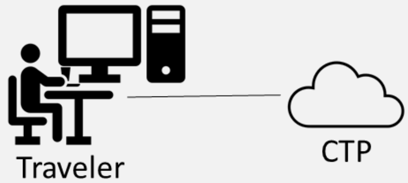
Lisa asks the app to call her support services lifeline -- the Call Center. When she speaks to the call center, the agent pulls up her account and submits a new trip plan for the community shuttle. The call agent generates a trip plan using her *volunteer home trip plan* origin and destination, human driver shuttle, with her preferences and pick up time "now". The Community Shuttle has a HDS available in 20 minutes, so the agent books the community shuttle, receives a confirmation, then cancels the PAL on-demand service. Lisa receives concurrent receipts on her phone, which she can see and confirm.

At the time of booking, a notification arrives on Lisa's app that her Community Shuttle HDS will arrive in 4 minutes at the entrance to Oishei, driver is Joe, half bus # 1234. She boards the vehicle and makes her way home.

6.2 User Focused Use Cases

6.2.1 UC 1: Register Profile and Preferences

UC 1	Register Profile and Preferences
Short Description	This use case describes the processes and interactions with travelers to set up a Complete Trip Platform user account. The function enables the account holder to select their travel preferences for types of navigation triggers, wayfinding notifications and alert communications. The functions also enable users to identify their preferences for mode, accessibility needs, and link other accounts with their CTP account.
Goal	The goal of this use case is to enable the traveler to register their travel preferences.
Constraints	• A traveler will require access to the internet through a computer, smartphone or the TIH to set up their account and use the services. Alternatively, a traveler can sign up and set up their profile by calling the Call Center. • Some travelers have multiple disabilities or language barriers. To this end, the types of constraints, information provisions, accommodations and accessibility costs will have a unique set of combined preferences. For example, an immigrant with low English proficiency (LEP) who has hearing loss may require symbols and sign language interpretation through a call center (rather than teletypewriter (TTY) or text-based notifications. • Preferences tend to limit trip alternatives. During the Agile process, priority preferences and limits to preferences will be discussed. • Some of the preferences may not be consistent or compatible with mobile handsets and operating system. To the extent possible, the development process will consider limitations of the smart phone at the time of the development process.
Geographic Scope	Data that feeds the CTP will be specialized only in the project geographic area – BNMC and surrounding neighborhoods. The CTP will cover all NFTA bus routes, but complete trip features will only cover the BNMC and surrounding neighborhoods.
Actors	• Traveler • Complete Trip Platform (including web and mobile app)

UC 1	Register Profile and Preferences
Illustration (example)	
Preconditions	1. Register and set up an account on the Complete Trip Platform (process will be determined as part of the Agile Development Process).
Main Flow	**Step 1:** The traveler with a set of preferences for their travel on the CTP. Travelers will select all the preferences that apply (in the order they desire): A) Traveler selects their preferred services, modes, user interface types including: • Preferences for accommodations by disability (and assistive device) • Preferences for types of intersection crossings (e.g., signalized, no more than 4 lanes), stop accessibility (e.g., shelters, benches), or accessible entrances (for vehicles, facility entrances, etc.) • Preferences for travel options during weather (e.g., no bicycles when there is precipitation -- rain or snow, door to door paratransit during cold and snowy weather) • Preferences for mode types (including PAL, Community Shuttle SDS or HDS, NFTA, etc.), maximum walking distance, shortest route, or fewest transfers, etc. • Preferred user interface (UI) notification type (e.g., smart phone voice, haptic, text, or connection to assistive device) • Preferences for unique names for frequently used trip plans, e.g., eye doctor, home, etc. B) Traveler links other mobility services to their CTP account. A set of providers will be offered initially to link to their account including PAL and other service providers. The details about how they link the accounts will be detailed as part of the Agile development process and once procedures and agreements are put in place between NFTA and third parties. C) Traveler may select an option to add trip support services including: • Call to guardian or call center. o Traveler will insert an identified third party and a method to access them into the form. • Be accompanied by caretaker or service animal. D) Traveler will select their preferred Navigation alerts • Turn-by-turn directions by alternative methods such as landmarks, turns, other markers or frequencies. E) Traveler will select their preferred Notification Types. Notification type preferences may include: • Orientation when alighting vehicle (or transition from one leg to another leg) for entrance, directions of appropriate seat or placement (e.g., senior seating or securement and type of securement)

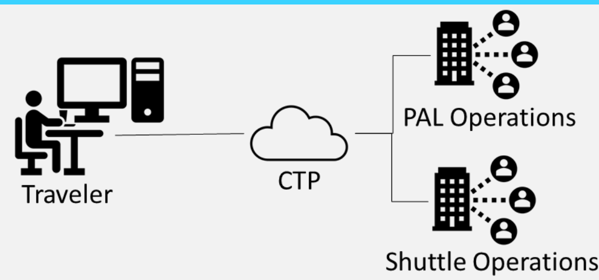
UC 1	Register Profile and Preferences
	• ETA for pickup (bus, light rail, Shuttle, PAL, circulator) • Information on delay for pickup • Disruption to trip plan (type) • Reroute (if left trip plan or disruption), and preferred mode for reroute option • Other notifications like emergency vehicle nearby or railroad crossing (will be detailed during Agile design phase) **Step 2:** When complete, Traveler will submit preferences**.** **Step 3:** The CTP will confirm the preferences showing a list of preferences with the following actions: Cancel, Edit, Accept**.** **Step 4:** Traveler select Accept to accept preference. **Step 5:** CTP stores profile.
Alternate Flow(s)	**Edit** Preferences **Step E-1:** Traveler selects **Edit** **Step E-2:** Summary table is rendered editable **Step E-3:** (go to Main Flow Step 1) **Cancel** Preferences **Step C-1:** (the CTP removes entries and returns to Login splash page).
Post-conditions	• Preferences will be saved and stored upon system Accept. All preferences will be protected and secured by the system. • During trip planning and travel monitoring, preferences will be transformed into route impedances for routing engine.
Information Requirements	• Types of assistive devices and their categories. • Available modes. • Library of notifications and types.
Rules and specialization for Underserved Populations	Based on user input some of the preferences are listed in this section. These preferences will be discussed as part of the Agile development process. Inclusion of the preference will be based on access to the information (by the traveler and system), impact to generate trip options, and priorities identified by user groups. **People with Mobility Disabilities** • Type of device and # of securement points • Average speed of device for crosswalks (and intersection crossing times) • Accessible pathways (esp. for people with walkers/rollators) and maximum walking times especially during cold and weather related (snow, rain) trips • Type of device determines type of vehicle is needed • Type of intersections (4 way, 5 way, etc.) • Stop accessibility including shelter, seating, accessible pathway, lighting, location of stop compared to shelter • Typically request audible and haptic (vibration) notifications **People who are Blind or have Vision Loss** • Path may need to be wide enough to accommodate traveler with guide dog or sighted guide. • Paths should not change surface type without warning and should be hard surface (not grass or unpaved)

UC 1	Register Profile and Preferences
	• Accuracy is critical; destination to end of each leg should be within 1 foot of transition or destination. • Turn by turn directions should be prompt and anticipated (see next bullet) and include information on next steps. • App text / image is customized for user need. Information may need to be presented audibly for people who are blind or have low vision. o For example, notification to alert traveler configurable number of seconds before turn, user gets notification and the frequency of notification updates before a turn (5 minutes before the turn, then 1 minute before the turn, then at the turn) • Display Information on signage with larger font size for people who have some sight ability, • Information on type of intersections (4 way, 5 way, etc.). • Information on stop accessibility including shelter, seating, accessible pathway, lighting, location of stop compared to shelter, and location of Braille signage if available in shelter. **People who are Deaf or have Hearing Loss** • Types of hearing aids and connection protocols. • Preference for notification (text with language preference, symbols, voice/auditory, sign language, haptic / vibration, video relay interpreting, etc.). • Preference for call center / IVR communication method. • Information on stop accessibility including shelter, seating, accessible pathway, lighting, location of stop compared to shelter, and location of auditory jack and/or talking sign. • Notifications for on-board transit announcement via mobile app. **People with Cognitive Disability** • Enable caregivers or guardians the ability to plan, support or accompany traveler on their journey. • Provide multiple path options for user is easiest and most comfortable for travel. • Stop accessibility including shelter, seating, accessible pathway, lighting, location of stop compared to shelter. • Customize language used in notifications for example: use “stop” rather than “don’t walk”. • Customize turn by turn directions with landmarks (e.g., turn left at Taco Bell). **Older Adults** • May use assistive devices similar to people with disabilities (rollator, cane). • Provide multiple path options for user is easiest and most comfortable for travel. • Information on stop accessibility including shelter, seating, accessible pathway, lighting, location of stop compared to shelter. **LEP** • Option to receive notifications in their native language, language in which they are proficient, or icons/symbols.

UC 1	Register Profile and Preferences
Related User Needs	UN-E-TP-5, UN-E-TP-8, UN-E-TP-11, UN-E-TE-10, UN-ES-TS-5, UN-E-TS-7, UN-S-SO-7, UN-S-SO-18

6.2.2 UC 2: Generate Trip Plan and Book a Trip

UC 2	Generate Trip Plan and Book a Trip
Short Description	This use case consists of functions for a traveler to plan a trip by inserting their origin and destination. They may customize this trip by selecting general preferences (e.g., modes, maximum walking distance, shortest trip, fewest transfers), or if they log in to their account use an existing trip plan or set of preferences for travel and notification. The traveler can also adjust their trip preferences and save the updated trip plan. In addition, as an account holder authorized to use registered mobility services such as PAL or Shuttle, the traveler can generate a complete trip plan with a trip leg that includes reservations and confirmation with the mobility service (PAL Direct or Shuttle).
Goal	The goal of this use case is to illustrate the traveler's ability to plan and book travel through the CTP based on their preferences.
Constraints	• Only registered CTP account holders will be provided trip plans that personalized their trip plan and provides them with notifications and the ability to personalize and save their trip plan. • Only registered CTP account holders who link their CTP account with other mobility service accounts will be able to use the reservations services to book a trip through the CTP. • At this time, payment is not being considered as part of the CTP subsystem. • Only registered CTP account holders will be able to hail a community shuttle.
Geographic Scope	Data that feeds the CTP will be specialized only in the project geographic area – BNMC and surrounding neighborhoods. The CTP will cover all NFTA bus and rail routes, but complete trip features will only cover the BNMC and surrounding neighborhoods.
Actors	• Traveler • Complete Trip Platform (including web and mobile app) • Shuttle reservations module • PAL Direct reservations module

UC 2	Generate Trip Plan and Book a Trip
Illustration (example)	
Preconditions	• If logged in to account, available linked mobility providers will also be made available for use (including use of the SOC reservations module) • Booking with PAL Direct requires certification and registration of account holder with PAL. • Booking Community Shuttle requires CTP account registration.
Main Flow	**A) The Traveler generates a trip plan and books a trip using the CTP. The following flow of actions are implemented:** 1. Traveler logs on to the CTP application (mobile or web) or calls the call center. 2. Traveler inserts their trip origin/destination, time and date, and updates preferences based on the trip. Alternatively, they may select a previously generated trip (using the saved trip). a. Selections for preferences will follow similar patterns as in Use Case 1. (Flow and specific interaction will be developed as part of the Agile Development Process). 3. Traveler generates their trip plan. a. The CTP uses the traveler preferences including the services for which they are eligible to generate, personalize and prioritize the trip plan options. i. CTP sends request for available services to the SOC with trip preferences. ii. The SOC returns list of options to CTP. iii. Once received, the routing engine will prioritize based on traveler preferences. iv. CTP ranks trip plans and presents to traveler. v. CTP includes a link to book a trip if PAL or Community Shuttle services are included in the trip plan. b. As a CTP account holder, traveler may book a community shuttle (see Use Case 6 for community shuttle logic for matching travelers to services). 4. Following display of their trip plan, Traveler will review and select trip plan. a. For PAL or Shuttle reservations, Travelers confirm trip segment, pick up / drop off locations, date and time information, other criteria and then select reservation services (Step C). b. Traveler may change the plan by updating preferences for this trip, and then they will select to re-generate trip plan (Go back to Step 2). **B) Travelers with CTP account will be prompted by the CTP to use any of the following services:**

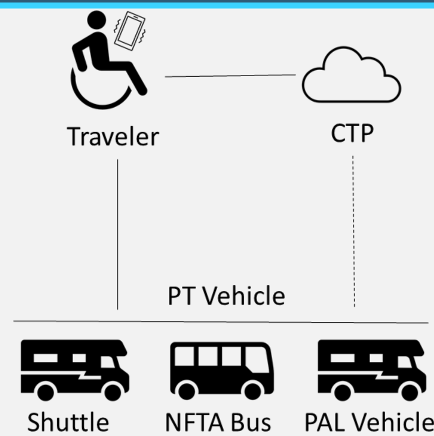
UC 2	Generate Trip Plan and Book a Trip
	1. Assign notifications and UI triggers through trip travel. 2. Play trip plan on channel requested in notifications. 3. Download and provide indoor trip planning wayfinding capabilities to facilities on their trip plan. 4. Agree to (opt in) to CTP tracking traveler or request that mobile app work off-line. 5. Save trip to future use and designate a nickname. **C) If the request trip requires reservations based on mobility mode selected (e.g., Shuttle or PAL), the traveler will interact with the specific provider's reservation services:** (Note: the specific interaction will be subject to institutional agreements between service provider and the CTP; this is a possible example of the interaction). 1. The traveler confirms the reservation needed based on the trip plan (including # passengers) (note: link information will be pre-inserted by the CTP app). a. CTP sends booking request to appropriate provider. b. Provider confirms eligibility of traveler services and sends a receipt and confirmation of the reservations (to app and / or contact information). c. Traveler views and accepts trip confirmation (or denial or present alternative date/time), if denied, reason for the denial will be included (e.g., not eligible for time or origin / destination). d. If traveler changes their plans, they may cancel or modify their reservations. (The timing and policies about canceling and modifying reservations will depend on provider provisions.).
Alternate Flow(s)	Cancel and Modify Functions: 1. Traveler selects their reservation from the CTP menu. 2. The app includes a button to view, edit or cancel the reservation. 3. Traveler selects one of the three buttons a. If View: CTP will show a summary of the reservations. Traveler will select okay to flow back to main screen. b. If Modify: Traveler is presented a form to change one or more of the fields (time/date, location, number of passengers). Steps will follow Step C above. c. If Cancel: Traveler is presented a form to cancel their reservation. The form is pre-filled by the CTP. The Traveler reviews and submits it. The CTP sends the form to the provider application and receives a confirmation. The CTP then sends a message to the Traveler that the complete trip plan requires update (transition to Step A of the Use Case).
Post-conditions	• If trip plan is saved, then it will be saved and associated with a traveler's account and can be recalled at any time. • During trip planning and travel monitoring, preferences will be transformed into route impedances for routing engine.
Information Requirements	• Reservations and confirmation • Trip plan

UC 2	Generate Trip Plan and Book a Trip
Rules and specialization for Underserved Populations	No special rules were identified.
Related User Needs	UN-E-TP-1, UN-E-TP-2, UN-E-TP-3, UN-E-TP-4, UN-E-TP-5, UN-E-TP-6, UN-E-TP-8, UN-E-TP-9, UN-E-TP-10, UN-E-TP-11, UN-E-TP-12, UN-E-TP-13, UN-E-TP-14, UN-E-TE-13, UN-S-SO-11, UN-S-SO-18.

6.2.3 UC 3: Public Transport Services

UC 3	Public Transport Services
Short Description	This use case describes the information provisions associated with accessing public transit mode options. These include NFTA bus, light rail, and PAL Direct, as well as Shuttle options that are included in these services. The services consist of hailing, boarding, traveling in and alighting these public transport vehicles. Note: Manual and physical accessibility issues are not included in this use case.
Goal	The goal of this use case is to show the types of information provision and services available through the CTP to accommodate travelers on public transport modes.
Constraints	• The types and frequency of real time information about vehicle location, load and usage depends on existing sensor and monitoring functions available on the vehicles. • Solutions will need to be addressed to access reservation and tracking services of the PAL reservations and operations functionality.
Geographic Scope	Data that feeds the CTP will be specialized only in the project geographic area – BNMC and surrounding neighborhoods. The CTP will cover all NFTA bus and rail routes, but complete trip features will only cover the BNMC and surrounding neighborhoods.

Actors	• Traveler with CTP mobile app
	• Public Transport (PT) Vehicles
	    ○ Shuttle (human and self-driving vehicles)
	    ○ NFTA Bus
	    ○ PAL Direct
	• CTP

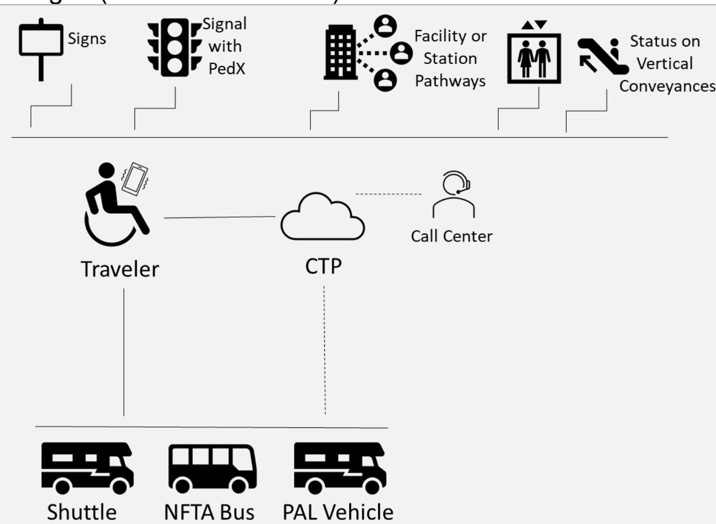
UC 3	Public Transport Services
Illustration (example)	
Preconditions	• Traveler plans a trip using the CTP app with tracking opt-in functionality and selected notification alerts. • If use PAL, then traveler linked their CTP account to PAL services. • If use Shuttle, then traveler registered for Shuttle services.

Main Flow	**[pre-boarding] Step A.** As the traveler waits or is approaching transit (including all mobility providers) pickup stop, the CTP detects their location and provides them with the following types of information and services based on personalized trip plan:
	1. Location of specific vehicle (by vehicle number, route, route direction and agency)
	    a. Estimated time of arrival at current location or specific stop.
	2. Location of stop, pick up location.
	3. Accessible path direction (based on traveler preferences if account holder) to stop or pick up location.
	4. Location/orientation to access wheelchair securement and type of securement when boarding vehicle.
	Note: boarding the vehicle (specifically SDS and HDS) are discussed in UC 7 and 8.
	
	[traveling] Step B. As traveler travels in the transit vehicle, the CTP provides the following types of information or services to the Traveler:
	1. Next stop information (stop and intersection, nearby landmarks).
	    a. For example: “This is your stop” notification.
	2. Next stop notification (optional feature, may not be implemented).
	    a. CTP detects travelers' current location and sends a notification to alight at next stop.
	
	[alighting] Step C: As traveler alights transit vehicle, the CTP provides the following types of information or services to the Traveler**:**
	1. Directions and notifications from the PT vehicle to next leg of journey (based on Traveler's preferences for wayfinding and navigation notifications:
	    a. Notifications may be needed including nearby cross streets, side of street, intersection crossing required.

UC 3	Public Transport Services
	b. Notification if entrance from NFTA station is locked or not accessible during travel time. c. Notification if other obstruction is detected that will alter their path.
Alternate Flow(s)	[pre-boarding] Potential notifications that may be sent by CTP to Traveler that may alter their pre-boarding / trip plan: 1. Information on whether the ramp and lift function on NFTA buses. 2. Information on access via elevator / escalator status for LR stations. [reporting] 1. Traveler can provide information on status of accessibility of PT services (pathways, pickup/drop off locations, etc.) -- See UC 5 for appropriate flows.
Post-conditions	CTP will need to record and apply “crowd-source” report of accessibility issues.
Information Requirements	• GTFS and GTFS-real time from all fixed route or shuttle modes. • GTFS-Flex and GOFS from all flex and micro transit modes. • Status and real time information on access (pathways) to stops and through stations including vertical conveyance status (and direction). • Message about number of occupied securements on vehicle.
Rules and specialization for Underserved Populations	Include information based on preferences for the following Underserved Population. **People with Mobility Disability** (using a wheelchair or mobility scooter) • Location and orientation to get to securement. • Type and operation of securement. • For Shuttle: audible announcement such as “door is open and ramp is extended, you may now board”. **All Underserved Populations** • Type of vehicle and vehicle number.
Related User Needs	UN-E-TP-7, UN-E-TP-11, UN-E-TP-12, UN-E-TP-13, UN-E-TE-5, UN-E-TE-6, UN-E-TE-13, UN-S-SO-1, UN-S-SO-11, UN-S-SO-18.

6.2.4 UC 4: Navigation

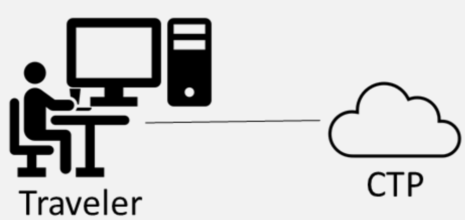
UC 4	Navigation
Short Description	This use case describes wayfinding and navigation on pathways to complete a trip. This use case consists of the use of the CTP when traveling including crossing intersections, traversing sidewalks, wayfinding to and through indoor facilities.

UC 4	Navigation
Goal	The goal of this use case is to show how travelers will navigate using the mobile app and wayfinding equipment along their complete trip.
Constraints	• There may not be GPS service available in buildings, in which case, a map of the facility or smart signs may be needed for wayfinding and navigation.
Geographic Scope	Data that feeds the CTP will be specialized only in the project geographic area – BNMC and surrounding neighborhoods. The CTP will cover all NFTA bus and rail routes, but complete trip features will only cover the BNMC and surrounding neighborhoods.
Actors	• Traveler with CTP mobile app • PT Vehicles • Sidewalk • NFTA Station • Indoor facility • Intersection signal system • Smart signs (indoor and outdoor)
Illustration (example)	
Preconditions	• A trip plan has been generated that provides turn by turn directions. • Traveler is using the CTP mobile app to travel
Main Flow	**The traveler opens the app and loads a trip plan to begin travel** 1. Synchronize the app to an assistive device (watch, hearing aid, etc.). 2. Load existing trip plan and begin trip. 3. Trip plan, using the appropriate UI (e.g., voice activated), begins with the turn-by-turn directions and notifications. 4. When next turn or event occurs, navigation directions will be sent or triggered by the mobile app. a. If traveler travels counter to the direction of travel, the app will alert the traveler that they are moving in the wrong direction. b. The traveler can override the turn directions if desired.

UC 4	Navigation
	When the trip plan includes a crosswalk (see Use Case 10), 5. A notification will alert traveler that they will cross the intersection. If they requested hands-off mode, the app will signal the pedestrian signal with a request for a walk signal. 6. The signal will respond with an acknowledgement that it received the request. 7. When the signal is green, the app will alert the traveler that they can now cross the intersection. It will send messages to the signal once the person starts to cross the intersection. 8. As the signal counts down, it will alert the app that the pedestrian walk is nearing its cycle end. **When the traveler is traversing the sidewalk or from parking lot** 9. The app will provide notifications on obstacles and detours on the public right of way including parking location to next leg or destination (and estimated walking times). 10. If the pathway is impassable (e.g., work zone), the app will provide a message with alternate directions. 11. The app will provide traveler with directions to an accessible entrance to their destination or through an accessible entrance to their destination. **Upon entering an indoor facility, the app will** 12. Orient the traveler on the direction to the TIH from where traveler can get more information on elevator, escalator, and permissible pathways. 13. If smart signs are installed in the facilities, the app will alert the traveler about any process to sync with the facility communications assets. 14. The wayfinding processes available in a facility are explained in Section 5.2.3.2.
Alternate Flow(s)	**When the trip plan includes a crosswalk,** 8. Alternatively, the pedestrian signal will remain active until the traveler has crossed the intersection. **Upon entering an indoor facility, the app will** 15. If no GPS or smart signs are available in a facility, the app will download a map prior to entering the facilities for use to find a destination.
Post-conditions	Track traveler conformance to the trip plan to assess their preferences and adjust their personalized trip plans.
Information Requirements	• Static and real time information on indoor facilities including wayfinding assets, status of vertical conveyances, pathways, and restrictions. Also, communications protocols to interfacing with wayfinding information systems. • Static and real time information on PROW including detours and construction on sidewalks. • Signal timing and interface protocols with pedestrian signal systems • Location of signal systems.

UC 4	Navigation
Rules and specialization for Underserved Populations	Include information based on preferences for the following Underserved Population. **People with Cognitive Disabilities or Older Adults** • Mobile App UI: Good contrast in logo, symbols rather than words, etc. • A traveler can access the call center for any information while journeying. • Pedestrian signal will monitor and change only after the traveler has crossed the intersection.
Related User Needs	UN-E-TP-8, UN-E-TP-9, UN-E-TE-5, UN-E-TE-6, UN-E-TE-7, UN-E-TE-9, UN-E-TE-11, UN-E-TE-14, UN-E-TS-4, UN-S-SO-2, UN-S-SO-3, UN-S-SO-4, UN-S-SO-6, UN-S-SO-15, UN-S-SO-16, UN-S-SO-18.

6.2.5 UC 5: Reporting and History

UC 5	Reporting and History
Short Description	This use case describes information provided to the traveler on the CTP that is available for account holders about trips they completed. In addition, the traveler can submit trip obstacles and improvements made during their journey. This provides a crowd-source approach to collecting information on accessibility status, like elevator outages, paths in the trip plan, etc.
Goal	The goal of the use case is to provide historical information on trip plans and their execution to the traveler, as well as enable the traveler to review trip plans and accessibility features along the trip legs.
Constraints	• Traveler requires access to the CTP account through the web or mobile app
Geographic Scope	Data that feeds the CTP will be specialized only in the project geographic area – BNMC and surrounding neighborhoods. The CTP will cover all NFTA bus and rail routes, but complete trip features will only cover the BNMC and surrounding neighborhoods.
Actors	• Traveler • Complete Trip Platform (including web and mobile app)
Illustration (example)	

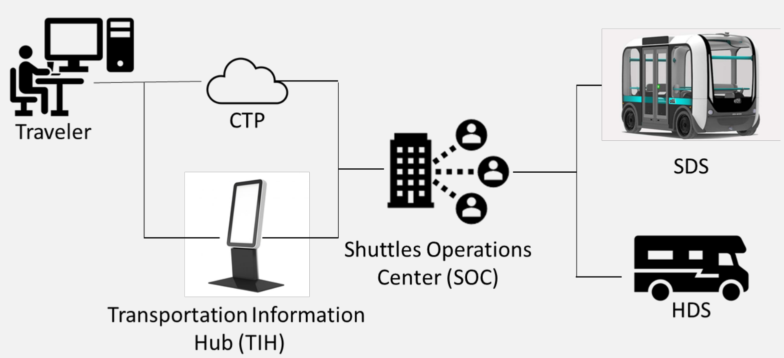
UC 5	Reporting and History
Preconditions	Register and set up an account on the Complete Trip Platform for trip history. Crowd-source function may be used by anyone using the CTP mobile app.
Main Flow	**The CTP provides a list of trip travel histories for the Traveler with an Account.** 1. Traveler selects 'view trip performance and history'. 2. A list of dates for travel histories are shown, when selected, the travel history shows a map of the trip, time from origin and destination and other pertinent information (to be determined during design/Agile process). **The CTP provides forms for submitting review, commendations and complaints about trip plans, infrastructure and travel notifications and preferences to any Traveler who uses the app.** 3. Traveler selects survey and completes form: a. Topic such as i. Public transit pick up / drop off location ii. Crosswalk iii. Sidewalk iv. Trip path v. Indoor navigation vi. Shuttle service vii. Other b. Location c. Scale of Accessibility (hard to easy) d. Issue / problem (open text)
Alternate Flow(s)	No alternative flows
Post-conditions	1. Information from review is consolidated and used to update routing algorithm.
Information Requirements	• Saved trip plans and travel histories • Surveys
Rules and specialization for Underserved Populations	• No special rules were identified.
Related User Needs	UN-E-TS-8, UN-E-TS-9, UN-S-SO-5, UN-S-BO-6, UN-S-BO-8, UN-S-BO-12,

6.3 Community Shuttle Operations Use Cases

6.3.1 Use Case 6: Ride-hailing Reservation and Dispatch

UC 6	Ride-hailing Reservations and Dispatch
Short Description	This use case describes several of the processes and functions of the SOC, and especially those that will be applied and activated when receiving a traveler requests service by the shuttles system.
Goal	The goal of this use-case is to allow a traveler to make a reservation for making a trip on one of the shuttles (that are part of the shuttles sub-system) that meets their accessibility requirements and preferences.
Constraints	• The trip origin and destination will have to be within the service area of the community shuttle subsystem shown on Figure 15. • The dispatching of the self-driving shuttle will require the route and conditions to be in compliance with the Operational Design Domain (ODD) of SDS. • Pick-up and drop-off for the SDS will occur only at designated points along the pre-defined set of streets making up the SDS route. • The request for service will have to be made via the CTP App (via call center operator, mobile app, web browser or TIH). • At least of the travelers requesting the service must be registered with the CTP and should have a valid traveler profile with preferences indicated.
Geographic Scope	Fruit-belt and BNMC (see the service area indicated in Figure 15.)

Actors	• SOC:
	  ○ SOC Reservation Management
	  ○ SOC Remote Monitoring
	  ○ SOC Routing/Scheduling Passenger Access
	  ○ Operational Design Domain Definition and Compliance
	• Human Driven Shuttle (HDS)
	• Self-driving Shuttle (SDS)
	• Traveler using the CTP (web, call center, mobile app, TIH)

Illustration (example)	

<table>
<tr><th>UC 6</th><th>Ride-hailing Reservations and Dispatch</th></tr>
<tr><td>Preconditions</td><td>The traveler is registered in the CTP specifically with Shuttle services
SOC has the ability to track and communicate with the shuttles to identify location, destination and available capacity</td></tr>
<tr><td>Main Flow</td><td>The traveler users CTP to place a request for service from the Shuttles Subsystem (see UC 2)
CTP communicates this information to SOC requesting availability for pickup/drop-off locations, times (ranges), service type, and preferences.
SOC responds with available options that meet request
SOC performs the following steps:
Identify location, destination, route, and available capacity of the human-driven and self-driving shuttles
Verify eligibility to use either the SDS or the HDS, based on user profile, preferences and ability.
Identify the shuttle which will be directed to satisfy the request
Traveler makes reservation on CTP and CTP sends reservation request to SOC
Note: availability options reviewed by Traveler are held for a specified number of minutes
Traveler selects option (see UC 2), and CTP sends request for reservations for option
The SOC will calculate updated or new route manifest and communicate route to the shuttle. In case of PWDs, the accessible entrance to the destination building is identified and used as the final destination for that passenger-trip.
Send trip reservation confirmation to traveler via CTP including times, locations, and set up alerts/notifications</td></tr>
<tr><td>Alternate Flow(s)</td><td>The traveler may cancel a reservation or modifying an existing reservation within a specified time period prior to pick up.
In case no shuttle can be identified that can satisfy the travel request within the constraints and requirements of the caller, the SOC will communicate a message stating “request cannot be satisfied within the requested time window for service. Earliest pick-up time feasible is XXX”. The user will then be allowed the option of either canceling the request or accepting the new estimated pick-up time.</td></tr>
<tr><td>Post-conditions</td><td>SOC will archive requests for service (to calculate on-time performance against actual service). The archived information can be later used to refine the planning and executing of the shuttle operations.</td></tr>
<tr><td>Information Requirements</td><td>Reservation requests including time, pickup and drop-off locations, number of passengers, accessibility preferences, etc.
Reservations confirmation with specific time / location of pickup and drop off, number of passengers, confirmation credentials, etc.
GTFS-Flex and GOFS from the flexible operations modes.
Shuttle information about current locations, schedule, occupancy and special conditions including number of occupied securements on the shuttle.</td></tr>
</table>

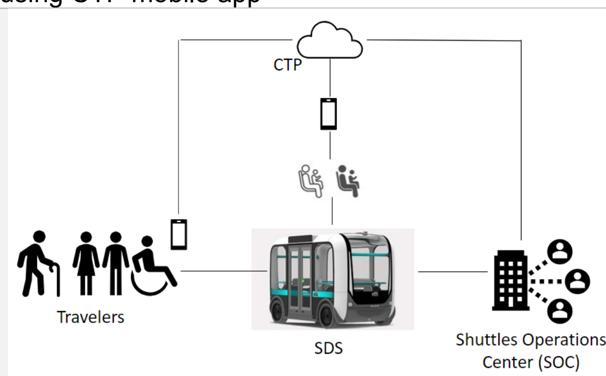
UC 6	Ride-hailing Reservations and Dispatch
	• Current schedules and routes for each shuttle during time period of request.
Rules and specialization for Underserved Populations	No special rules were identified.
Related User Needs	UN-E-TP-1, UN-E-TP-2, UN-E-TP-3, UN-E-TP-5, UN-E-TP-7, UN-E-TP-10, UN-E-CTP-11, UN-E-TP-12, UN-E-TE-1, UN-E-TE-2, UN-E-TE-3, UN-E-TE-9, UN-S-BO-3, UN-S-BO-4, UN-S-BO-5

6.3.2 Use Case 7: Passenger Pick-up, Securement, Travel and Drop-off via the SDS

UC 7	Passenger Pick-up, Securement, Travel and Drop-off via a SDS
Short Description	This use case describes several of the processes and functions of the Shuttles Subsystem which will be applied and activated when a traveler boards a SDS, secures herself onboard the vehicle, travels on the SDS, and finally gets off the SDS at their final or intermediate destination.
Goal	The goal of this use-case is to allow travelers whose preferences and abilities are compatible to safely board the shuttle, apply the appropriate securement mechanism for passengers on a wheelchair, receive updates and pertinent information along their journey, as well as safely get off the shuttle at their final destination.
Constraints	• The pick-up and drop-off locations will have to be within the service area of the micro-transit subsystem shown on Figure 15. Moreover, the use of the self-driving shuttles will have to be constrained by the conditions of the ODD for the shuttle. • Pickup and drop-off locations will have to be appropriately designed to allow for the shuttle's accessibility mechanisms to deploy. • Travelers are able to get to the designated pick-location for the SDS service (e.g., by walking a few blocks to the designated location), as well as able to get from the drop-off point to their destination. • Users need to have an appropriate user profile within CTP, including information on their residence, preferred pick-up point (including which side of the road they live), and their accessibility needs. This is important to decide whether a SDS or a HDS should be directed to satisfy their travel request. • Passengers on wheelchairs boarding the SDS are assumed to be able to utilize the securement mechanism onboard the SDS. • At this time, payment is not being considered as part of the Shuttles subsystem.

UC 7	Passenger Pick-up, Securement, Travel and Drop-off via a SDS
Geographic Scope	Fruit-belt and BNMC (see the service area indicated in Figure 15).

Actors	• Self-driving Shuttles (SDS):
	  o Shuttles Pick-up/boarding, drop-off/alighting monitoring
	  o Shuttles Accessibility Support
	  o Shuttle Wheel-chair securement
	  o SDS Passenger Information
	  o SDS Steward
	• SOC:
	  o Remote monitoring
	• Traveler using CTP mobile app

Illustration (example	
Preconditions	• The traveler has an account or registered in CTP, and specifically with Shuttle services with the details described above. • SOC has the ability to track, communicate and remote monitor the shuttles.
Main Flow 1 (SDS)	1. Upon the shuttle's arrival at the designated (pre-defined) pick-up location, which may be a few blocks away from the traveler's residence, the shuttle will stop, and open the doors. 2. The shuttle, then sends a confirmation message to the SOC indicating arrival (the SOC would then communicate to the traveler, via their preferred UI, the arrival of their shuttle), deploy the needed accessibility mechanism, and provide tactical or audible clues, if needed, to guide travelers with disabilities to the shuttle door. The SOC and SDS will check that the traveler is appropriately secured before closing the doors and departing. 3. Shuttle will send a confirmation message to SOC to confirm pickup and update available capacity, including available seats and securement mechanisms. 4. The SDS checks the "health" of its different sensing, perception, and control subsystems before starting. Once status confirmed, the shuttle starts driving in autonomous mode. As part of this deployment and evaluation phases, a human steward will be always present on-board to

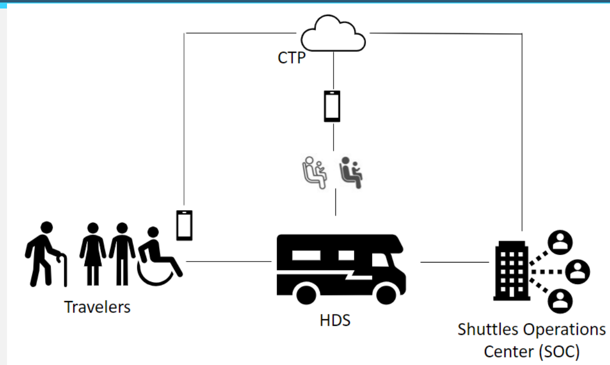
UC 7	Passenger Pick-up, Securement, Travel and Drop-off via a SDS
	intervene in case of any emergencies or situation calling for disengaging the autonomous system. 5. While enroute, the CTP and/or shuttle information subsystem provides the passengers with continuous information regarding the progress of the trip, including information about key landmarks that the shuttle has just passed. This is important especially in case the shuttle is transporting passengers who are blind or have low vision. 6. In case a passenger intends to transfer to another transportation mode at the end of their shuttle trip (e.g., connect to the subway or fixed bus service), the CTP will provide the passenger with information about the expected arrival time of the mode of transportation they intend to transfer to at the terminal located at the end point of their shuttle trip segment. 7. X minutes before the arrival of the shuttle at a scheduled stop, the shuttle and/or CTP announces to the passengers the upcoming stop, to allow passengers who need to get off to get ready to disembark the shuttle. 8. Passengers on-board the shuttle will be provided with a means to allow them to communicate with the human operator in the SOC to report any emergencies or needs. 9. At the traveler's destination, the shuttle stops, opens its doors, deploys accessibility mechanisms, if needed, to allow the traveler to get off the shuttle. 10. The shuttle monitors the alighting process, and once it confirms that the traveler is safely off the shuttle, and cleared the path of the vehicle, the shuttle resumes its trip to the next destination along its trip chain.
Alternate Flow(s)	In case the traveler requesting the service does not show up at the pick-up locations within a pre-determined number of minutes of the shuttle arrival, the shuttle will close the doors, communicate to SOC to indicate a "no-show" traveler, and resume its journey.
Post-conditions	Status of the shuttle in terms of available capacity and available securement mechanisms is updated. New route and new destination are established for the shuttle. Information regarding dwell time, boarding time, time needed for securement are recorded and archived for future analysis, intended to refine future shuttle operations.
Information Requirements	• A detailed 3-D Map of the service area for the SDS localization algorithms. • Information about key intersections and landmarks along the shuttle's route for announcements aimed at informing passengers with visual impairments of the progress of the trip.

UC 7	Passenger Pick-up, Securement, Travel and Drop-off via a SDS
	• Information about the arrival time of other transportation modes (e.g., subway, fixed route-bus) at a passenger's trip end point where they intend to transfer to another transportation mode.
Rules and specialization for Underserved Populations	• As noted above, travelers with vision loss, and whose preferences and abilities are compatible with the use of a SDS, may need specific tactical or audible clues to guide their pick-up and drop-off processes. • As also noted above, travelers on a wheelchair will need to utilize the accessibility and securement functions of the shuttle.
Related User Needs	UN-E-TP-4, UN-E-TP-10, UN-E-TE-1, UN-E-TE-2, UN-E-TE-10, UN-E-TS-1, UN-E-TS-2, UN-E-TS-3, UN-E-TS-6, UN-S-SO-14, UN-S-SO-15, UN-S-SO-16

6.3.3 Use Case 8: Passenger Pick-up, Securement, Travel and Drop-off via a Human-Driven Shuttle

UC 8	Passenger Pick-up, Securement, Travel and Drop-off via a HDS
Short Description	This use case describes several of the processes and functions of the Shuttles Subsystem, which will be applied and activated when a traveler boards an HDS, has her mobility aid mechanism secured, travels on the shuttle, and finally gets off at their final destination.
Goal	The goal of this use-case is to allow all travelers, including persons with disabilities (PWDs), to safely board the HDS, secure a wheelchair onboard the shuttle, get information about the trip progress during the trip, and safely get off the shuttle at their final destination.
Constraints	• The trip start and end points will have to be within the service area of the micro-transit subsystem shown on Figure 15. • Users need to have an appropriate user profile within CTP, including information on their residence, preferred pick-up point (including which side of the road they live), and their accessibility needs. • At this time, payment is not being considered as part of the Shuttles subsystem.
Geographic Scope	Fruit-belt and BNMC (see the service area indicated in Figure 15).

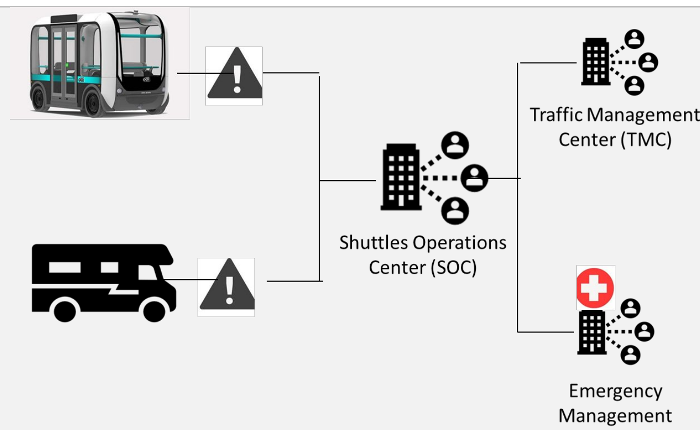
Actors	• HDS:
	    ○ Passenger Information Management
	    ○ Shuttles Accessibility Support
	    ○ Shuttle Wheel-chair securement
	• SOC
	    ○ Remote monitoring
	• Traveler using CTP mobile app

UC 8	Passenger Pick-up, Securement, Travel and Drop-off via a HDS
Illustration (example)	
Preconditions	• The traveler has an account or registered in CTP, and specifically with Shuttle services with the details described above. SOC has the ability to track, communicate and remote monitor the shuttles.
Main Flow 1 (HDS)	1. Upon the shuttle's arrival to pick-up a passenger, the driver stops, opens the shuttle doors, sends a confirmation to the SOC that they had arrived, and deploys the needed accessibility mechanism (e.g., ramp). 2. SOC would then communicate to the traveler, via their preferred UI, the arrival of their shuttle. 3. If needed, the driver helps the traveler gets onboard the shuttle, and make sure the traveler is safely secured onboard. 4. Driver closes the door, sends a confirmation message to SOC to confirm pickup and update available capacity, including available seats and securement mechanisms. 5. While enroute, the shuttle provides the passengers with continuous information regarding the progress of the trip, including information about key landmarks that the shuttle has just passed. This is important especially in case the shuttle is transporting passengers with visual impairments. 6. In case a passenger intends to transfer to another transportation mode at the end of their shuttle trip (e.g., connect to the subway or fixed bus service), the CTP will provide the passenger with information about the expected arrival time of the mode of transportation they intend to transfer to at the terminal located at the end point of their shuttle trip segment. 7. X minutes before the arrival of the shuttle at a scheduled stop, the CTP announces to the passengers the upcoming stop, to allow passengers who need to get off to get ready to disembark the shuttle.

UC 8	Passenger Pick-up, Securement, Travel and Drop-off via a HDS
	8. At the traveler's destination, the shuttle stops, opens its doors, deploys accessibility mechanisms, and, if needed, the shuttle driver helps the traveler get off the shuttle. 9. The driver monitors the alighting process, and once the driver confirms that the traveler is safely off the shuttle, and cleared the path of the vehicle, the driver resumes the trip to the next destination along the trip chain.
Alternate Flow(s)	In case the traveler requesting the service does not show up at the pick-up locations within a pre-determined number of minutes of the shuttle arrival, the driver will close the doors, communicate to SOC to indicate a "no-show" traveler, and resume its journey.
Post-conditions	Status of the shuttle in terms of available capacity and available securement mechanisms is updated. New route and new destination are established for the shuttle. Information regarding dwell time, boarding time, time needed for securement are recorded and archived for future analysis, intended to refine future shuttle operations.
Information Requirements	• Information about preferred pick-up point, the side of the street where pick-up point is located, accessibility needs of the passenger requesting the service.
Rules and specialization for Underserved Populations	• Some travelers with disabilities may need help from the driver in boarding or alighting from the shuttle, and/or help with wheelchair securement.
Related User Needs	UN-E-TP-4, UN-E-TP-10, UN-E-TE-1, UN-E-TE-2, UN-E-TE-10, UN-E-TS-1, UN-E-TS-2, UN-E-TS-3, UN-E-TS-6, UN-S-SO-14, UN-S-SO-15, UN-S-SO-16

6.3.4 Use Case 9: Manage Incidents

UC 9	Manage Incidents
Short Description	This use case describes the processes and functions that will be activated by the shuttles subsystem to manage shuttle-related incidents. The incidents may involve the environment around the shuttle (e.g., inclement weather), the vehicle itself (a malfunction) or travelers onboard the shuttle.
Goal	The goal of this use-case is to describe how the system will handle t different types of incidents, to ensure the safety of all travelers on the transportation network.

<table>
<tr><th>UC 9</th><th>Manage Incidents</th></tr>
<tr><td>Constraints</td><td>Only a subset of incidents is considered here.</td></tr>
<tr><td>Geographic Scope</td><td>Fruit-belt and BNMC (see the service area indicated in Figure 15).</td></tr>
<tr><td>Actors</td><td>HDS:
Shuttles engine and maintenance monitoring
SDS:
Shuttles vehicle control
Shuttles engine and maintenance monitoring
SOC:
Remote monitoring
Incident Management
TMC
Emergency Management</td></tr>
<tr><td>Illustration (example)</td><td>
</td></tr>
<tr><td>Preconditions</td><td>The shuttle system is in operations and there are active requests for service which need to be handled</td></tr>
<tr><td>Main Flow 1 (SDS)</td><td>1. The driving environment presents a situation that exceeds the capabilities of the autonomous driving algorithm (e.g., complex traffic scenario, unexpected change in the driving environment because of weather or road work):
For the duration of the current project, all SDS will have a human steward onboard whose responsibility will be to intervene and take off control from the autonomous system when presented with such situations. For the long term, there may be a means to remotely control the shuttle from the SOC.
The human steward will remain in control under the situation no longer exists.</td></tr>
</table>

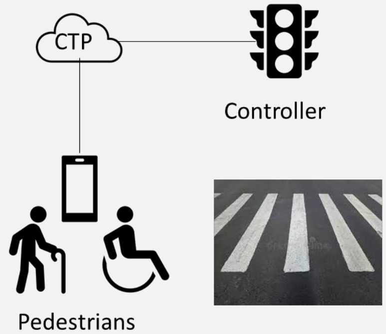
UC 9	Manage Incidents
	○ If/when AV technology matures to the level that a human steward is not required onboard, and when AV regulations and laws allow it, the SDS will be programmed to pull over in such cases, stop, and communicate with the SOC.
Alternate Flow(s)	• A malfunction of a cyber (e.g., a sensor) or physical (i.e., the lift or wheelchair securement mechanism) element on board the SDS: ○ Before starting a trip, the shuttle will check the "health" of both its cyber as well as physical subsystems. Operations of that particular shuttle will only be allowed if our subsystems are functioning as intended. ○ When the Shuttle detects a malfunction, that particular shuttle will be taken to repair to fix the problem. The SOC will take into account the reduced capacity of the system when taking and confirming reservations. ○ If the malfunction takes place in the midst of a trip, with travelers on board, the shuttle pulls over and stops. SOC then dispatches an alternate shuttle to transport the passengers, and the affected shuttle is taken to repair. • A malfunction of the HDS or its accessibility or securement mechanisms: ○ If this happens before start of daily operations, the shuttle is taken for repair, and the SOC trip reservation functions take note of the reduced capacity of the system. ○ If it is detected in the midst of operations with travelers onboard, the shuttle pulls over and stops. SOC then dispatches an alternate shuttle to transport the passengers, and the affected shuttle is taken to repair. ○ If a malfunction is detected that particular shuttle will be taken to repair to fix the problem. The SOC will take into account the reduced capacity of the system when taking and confirming reservations. • Incidents involving a health emergency for a passenger on board the shuttle ○ In the case of a SDS, when the human steward onboard the shuttle or the operators at the SOC detect a health emergency for a traveler (e.g., an onboard traveler may contact the SOC, or the SOC, through its remote monitoring capability may detect the emergency), the SOC sends a command for the SDS to stop at the nearest safe spot. ○ SOC/the shuttle will contact emergency management to describe the nature of the incident and give the exact location for the shuttle.

<table>
<tr><th>UC 9</th><th>Manage Incidents</th></tr>
<tr><td></td><td>Emergency management will deploy the appropriate vehicle, first responder, and EMT personnel to the scene.
In the case of a HDS, when the driver detects a health emergency for a traveler onboard the shuttle, the driver stops the shuttle and contacts SOC.
Cases where there is a major traffic accident or incident along the shuttle path.
The Traffic Management Center (TMC) communicates to the SOC information about the incident detected and verified.
SOC calculates alternate routes, taking into account the current routes and destinations of travelers on board the SDS, and communicates that information to the SDS.
When incident is cleared and traffic conditions return to normal, TMC communicates that to SOC. SOC and shuttles then resume normal operations and route choices.</td></tr>
<tr><td>Post-conditions</td><td>None identified</td></tr>
<tr><td>Information Requirements</td><td>Information about any major traffic incidents within the service area of the shuttle’s subsystem.
Information about work zones within the service area of the shuttles.
Weather conditions and forecasts.</td></tr>
<tr><td>Rules and specialization for Underserved Populations</td><td>When responding to a health emergency for a PWD, Emergency Management may benefit from health-related information about the person’s disability.
When re-routing a shuttle, because of an incident, PWDs need to be kept informed about the change in the route. In addition, the system needs to ensure PWDs are eventually dropped off at the accessible entrance to their final destination.</td></tr>
<tr><td>Related User Needs</td><td>UN-S-SO-17, UN-S-BO-2, UN-S-BO-8, UN-S-BO-12, UN-S-BO-13</td></tr>
</table>

6.4 Smart Infrastructure Use-cases

6.4.1 Use Case 10: Intersection Pedestrian Crossing (PedX) Request

UC 10	PedX Request
Short Description	This use case describes the transmission of a PedX request message from the CTP to the traffic signal controller. This use case supports the intersection crossing system. Note: this use case is modeled after the NTCIP 1211 Signal Control and Prioritization architecture and use case scenarios. The terms Priority Request Generator (PRG), Priority Request Server (PRS) and Coordinator (CO) are use case actors in the NTCIP 1211 and will be used in this use case even as the PedX request is a simple request and does not include a request for priority.
Goal	The goal of this use case is to provide a hands-off PedX Signal Actuation Request.
Constraints	• The communications latency between the generator and server is low. • The CTP Mobile app has security clearance to request actuation. • The PRG will transmit the PedX request message at a rate agreed to by the partner agencies and no more than once every 5 seconds.
Geographic Scope	The following two intersections on BNMC: • Main/Best Intersection • Ellicott/High Intersection
Actors	• CTP Mobile APP (Traveler) – serving as Priority Request Generator (PRG), i.e., a logical or physical entity that initiates a priority request. • Receiver (Communications Gateway). • Traffic Cabinet – serving as Priority Request Server (PRS), i.e., a logical or physical entity that manages and prioritizes one or more requests. Definitions from National Transportation Communications for ITS Protocol (NTCIP) 1211 – Object Definitions for Signal Control and Prioritization (SCP) (2014).

UC 10	PedX Request
Illustration (example)	
Preconditions	• The PRG based on programmed criteria and under the agreed business rules, determines pedestrian crossing signal priority is desired. • The CTP mobile app has been programmed with the communications address of the Controller Receiver for the intersection where PedX is available and the priority strategies available for that controller. • The Controller has been configured with the priority strategies available and is properly configured with the PRS. • Timely and reliable pedestrian data is available and can be used to generate the PedX request message and subsequent update messages.
Main Flow	1. The use case begins when the traveler approaches an intersection crossing and their trip plan directs them to cross the intersection. Their CTP trip plan (PRG) determines a priority request is desired. 2. The PRG generates a PedX request message (e.g., similar to the prgTSPRequest) to the PRS. The request message contains the identifier of the mobile app that is desired for PedX, a request identifier, the priority strategy requested (crosswalk to actuate the pedestrian signal), time of service requested (TSD), and the time of estimated departure (TED). 3. The PRG generates a PedX request message and transmits it to the PRS at a configurable TSD threshold value (e.g., 30 seconds before the traveler arrives at the intersection). 4. The Controller logs the time the PedX request message is transmitted to PRS. 5. The PRS receives and logs all transactions to and from the PRG and Controller (between the PRS and these entities as well as from these entities from external sources).

UC 10	PedX Request
	6. As the traveler continues traveling toward the intersection or waits at the intersection, the PRG (CTP app) will transmit a PedX request status message. A PedX request status message contains the identifier of the mobile app that is desired for PedX, a request identifier, the priority strategy requested (crosswalk to actuate the pedestrian signal), TSD, and the TED. 7. The PRS receives the PedX request status message. 8. The PRS receives and logs all transactions to and from the PRG and Controller (between the PRS and these entities as well as from these entities from external sources). 9. The flow repeats with Step 2 continuously as the PRG continues transmitting a PedX request status message; the PRS continually tracks the traveler and calculates TSD/TED. These status messages, to inform the PRS and Controller of changes to the pedestrian's anticipated arrival, are generated and transmitted to the PRG on an as-needed basis. 10. The signal controller services PedX at the appropriate time, as the traveler is waiting at the intersection. 11. The PRG output and PedX request messages continues until the pedestrians(s) have cleared the intersection (e.g., TED = 0), then the PRG sends a message that indicates that the traveler cleared the crosswalk.
Alternate Flow(s)	**Alternative to Step 6:** The PRG generates a PedX request cancel message to the PRS. The PedX request cancel message contains similar fields as the TSP request message is used to indicate that the request is no longer needed**.**
Post-conditions	None
Information Requirements	PedX request
Rules and specialization for Underserved Populations	None identified as yet.
Related User Needs	UN-E-TP-8, UN-E-TE-8, UN-E-TE-10, UN-S-SO-2, UN-S-SO-3, UN-S-SO-18.

7 Summary of Impacts

The section describes the operational impacts of the new system on the users, developers, maintainers, and other agencies and organizations involved with the system. It also explains how the transition periods will impact system stakeholders and users moving from the current system environment to the new system including training and other impacts. This information is intended for agencies, organizations and users involved in or effected by the project to gain a sense of the impact of the new system and plan and prepare for potential impacts and changes.

7.1 Operational Impacts

The proposed changes will directly impact operations for most of the key stakeholders as described below.

7.1.1 NFTA Paratransit Operations

Table 18 details how the proposed system will directly impact NFTA Paratransit operations.

Table 18. Operational Impacts to NFTA PAL.

Field	Operational Impact
Interfaces/communication with primary or alternate systems or centers	• New interfaces (APIs) will be developed to share information with the new system. • Provide improved linkage between paratransit services and other mobility modes (light rail, shuttle, and indoor navigation). • Off-load some functionality to the CTP app, although during testing it may require staff monitoring of the reservations.
Procedure	• Integrating PAL reservations with the CTP for a select group of eligible travelers. • Operational procedures will need to be put in place to validate reservations, cancellations and no-shows.
Data sources	• New data coming from the ITS4US system and its components.
Quantity, type, and timing of data to be input into the system	• While changes in data quantity, type and timing are expected, the impact in operations is not expected to be significant. Data characteristics will be determined during the design phase.
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• No change due to the system to PAL operations.
Methods for providing input data if the required data are not readily available	• PAL vehicles will need to have open data feeds for the CTP app to provision status information to be sent to PAL customers at their preferred update rates.

Field	Operational Impact
	• Customers will need to opt in to accessing this information. This may require additional institutional agreements to promulgate the coordination between systems. • If input data is not readily available, then the CTP system would have to push travelers outside the system to book their pal trips.
Operational risks	• Introduction and operation of the community shuttle may create confusion for travelers who are PAL-eligible and in the zone of the shuttle operations on which service to use and when.

7.1.2 NFTA Operations

Table 19 details how the proposed system will directly impact NFTA operations.

Table 19. Operational Impacts to NFTA.

Field	Operational Impacts
Interfaces/communication with primary or alternate systems or centers	• New interfaces with the ITS4US system and its components especially around fixed route services (schedules, real-time locations), elevator and escalator outages.
Procedure	• The community shuttle will require an alternative/additional dispatch, operations and route adherence approach. Depending on how the shuttle is operated, NFTA either has to operate or monitor operations of the shuttle. • Other downstream system like NTD reporting, standard operating procedures, performance measures and other operational procedures will need to be altered or defined.
Data sources	• New data coming from the ITS4US system, and its components will support greater understanding of transit use in the project area. NFTA will also see additional emphasis on timelier reporting of escalator and elevator outage data. • Many of the user needs require the provision of real time information including real time collection of elevator/escalator outages at stations in the project area. While the information is currently available, additional and/or updates the current processes may be required to increase the latency of reporting from NFTA staff. • Additionally, many of the user needs require the collection of transit stop, stations and shelter information including access to and from stops (surface, smoothness, lighting, bench, etc.), stop conditions, and other information.
Quantity, type, and timing of data to be input into the system	• While changes in data quantity, type and timing are expected, the impact in operations is not expected to be significant. Data characteristics will be determined during the design phase.
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• Closely related to outages is the identification of preferred alternatives when such outages happen. Currently, the information is in static pdf

Field	Operational Impacts
	formats and will likely have to be converted into a format that is suitable for the CTP. • With the SDS in operations, incident and emergency procedures will need to be coordinated with traffic operations and emergency and law enforcement agencies to manage incidents (examples are discussed in Use Case 9 (Section 6.3.4).
Methods for providing input data if the required data are not readily available	• If real-time Input data from NFTA is not available, the CTP can use static data which are available, but it would severely compromise the ability to provide accurate trip plans.
Operational risks	• Introduction and deployment of the community shuttle is new to NFTA since they have not operated a demand-responsive micro transit system before. Standard operating procedures are not defined and would be new to the agency and its staff.

7.1.3 City of Buffalo Operations

Table 20 details how the proposed system will directly impact the City of Buffalo operations.

Table 20. Operational Impacts to City of Buffalo.

Field	Operational impact
Interfaces/communication with primary or alternate systems or centers	• Two intersections will have the ability to communicate with the CTP app.
Procedure	• Enabling automatic or hands-free activation of the pedestrian signal at intersections may impact the pedestrian timing cycles. The review will require the city to update pedestrian timing cycles and perhaps update the interface protocols to actuate the signal. With the Middle Main Street construction project underway, reviewing the timing plans to promote "pedestrian friendly" signal operations will support this project as well.
Data sources	• New data coming from the ITS4US system, and its components might be beneficial to City of Buffalo in understanding trip needs and pedestrian activity around the two intersections. • Additional data processes to monitor and report localized impacts like road conditions, construction, incidents may need to be updated to account for the higher frequently and accuracy needed to support elements of the CTP.
Quantity, type, and timing of data to be input into the system	• While changes in data quantity, type and timing are expected, the impact in operations is not expected to be significant. Data characteristics will be determined during the design phase.
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• Any intersection outage at the two project intersections needs to be communicated with the CTP. In addition, City of Buffalo would also need to be aware of ongoing shuttle operations, especially the use of SDS on city roadways.

Field	Operational impact
Methods for providing input data if the required data are not readily available	• The CTP is highly dependent on collecting accurate and navigable sidewalk and PROW features and condition information to provide to travelers. The need for the collection, and management of the information may be new to the city. To that end, a plan for collecting, curating and distributing sidewalk and public right of way accessibility information helpful. In addition, other downstream uses for the data including contributing to contribute to ADA Transition Plan may be incorporated into the plan.
Operational risks	• Two operational risks are identified. • Intersection safety- The use of the system components should not reduce the safety performance of the intersection. • SDS operational performance – Any negative interactions of the SDS with traffic and vulnerable road users will pose an operational risk to the city.
Other	• The proposed system has a dependency on an ongoing construction project. Regular coordination between the construction project teams and the system developers are needed in both the planning and the construction phases.

7.1.4 NYS Department of Transportation

Table 21 details how the proposed system will directly impact NYSDOT operations.

Table 21. Operational Impacts to NYSDOT.

Field	Operational Impact
Interfaces/communication with primary or alternate systems or centers	• The CTP is likely to leverage software systems and tools available through the NYSDOT mobility management programs including the Open Trip Planner.
Procedure	• The CTP will be another tool for TDM services offered by the 511NY Rideshare program in the Buffalo region through partners like GO BNNC.
Data sources	• New data coming from the ITS4US system and its components.
Quantity, type, and timing of data to be input into the system	• While changes in data quantity, type and timing are expected, the impact in operations is not expected to be significant. Data characteristics will be determined during the design phase.
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• No impact.
Methods for providing input data if the required data are not readily available	• No impact.
Operational risks	• No impact.

7.1.5 NYS Department of Motor Vehicles

Table 22 details how the proposed system will directly impact NYS Department of Motor Vehicles (DMV) operations.

Table 22. Operational Impacts to NYS DMV.

Field	Operational Impact
Interfaces/communication with primary or alternate systems or centers	• No direct interface is expected.
Procedure	• The SDS is relatively new to the region. Licensing and regulations are required to ensure safe operations. • Operating the SDS in the BNMC campus and Fruit Belt region may need additional approvals, procedures and regulations.
Data sources	• Reports on SDS performance and data may be required by DMV and specific data needs determined by DMV or other entity involved in SDS regulation.
Quantity, type, and timing of data to be input into the system	• No impact
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• No impact.
Methods for providing input data if the required data are not readily available	• No impact.
Operational risks	• SDS operational performance – Any negative interactions of the SDS with traffic and vulnerable road users will pose an operational risk to the DMV or the regulatory entity.

7.1.6 Emergency and Law Enforcement Entities

Table 23 details how the proposed system will directly impact Emergency and Law Enforcement Entities operations.

Table 23. Operational Impacts to Emergency and Law Enforcement Entities.

Field	Operational Impact
Interfaces/communication with primary or alternate systems or centers	• To that end, emergency and law enforcement agencies may work with Complete Trips development team to build and monitor a SDS tracking capability.
Procedure	• Law enforcement entities may need to track the shuttles to monitor their activities, particularly since they are new to road network.

Field	Operational Impact
	• Law enforcement entities will also need to understand how travelers with disabilities are using the CTP system especially around the wayfinding and intersection crossing functions.
Data sources	• N/A
Quantity, type, and timing of data to be input into the system	• N/A
Data storage and privacy requirements	• Same as existing.
Modes of operation based on emergency, disaster, or accident conditions	• With the SDS in operations, incident and emergency procedures will need to be coordinated between the SOC/SDS and traffic operations and emergency and law enforcement agencies to manage incidents (examples are discussed in Use Case 9 (Section 6.3.4). • If the SDS has an emergency alert button, the emergency and law enforcement agencies may need to set up a response plan for deal emergency situations.
Methods for providing input data if the required data are not readily available	• N/A
Operational risks	• N/A

7.1.7 BNMC Entities

Table 24 details how the proposed system will directly impact BNMC entities operations.

Table 24. Operational Impacts to BNMC Entities.

Field	Operational Change
Interfaces/communication with primary or alternate systems or centers	• Upgrades to internal and external signage and wayfinding may be required of the campus entities. • Smart signs will be installed on several partner facilities to support indoor navigation through the CTP app.
Procedure	• Transportation coordinators need to understand how to leverage the CTP for their needs for travel planning and support to their customers. • In the long-term, operational impacts may include maintenance of indoor navigation and accessible path elements of the proposed concepts.
Data sources	• Building access plans and maps, and indoor navigation data will need to be collected and shared with the CTP system during the development phase and updated when conditions change.
Quantity, type, and timing of data to be input into the system	• This will be identified in the design stage.
Data storage and privacy requirements	• No significant impact anticipated.

Field	Operational Change
Modes of operation based on emergency, disaster, or accident conditions	• No impacts.
Methods for providing input data if the required data are not readily available	• N/A
Operational risks	• No major risks anticipated.

7.2 Organizational Impacts

New systems impact organizations differently. The proposed changes will directly impact organizational resources and training needs as follows (Table 25):

Table 25. Operational Impacts to BNMC Entities.

Agency	Organizational Impact
NFTA Paratransit and Operations	• Shuttle operators will need training on how to verify traveler reservations, accessibility needs including announcements and signage, routing, and more. • Outreach and training efforts will need to be initiated to familiarize NFTA operators with the new services through the CTP, Shuttle and smart infrastructure subsystem. A clear set of marketing guidelines (e.g., ready-made templates, branding and program information) can be used for outreach to customers. The outreach will need to accommodate the various user traveler user groups in the stakeholder description. • Systems and process upgrades need to be coordinated with NFTA staff who need to understand how information from their systems will be used in the CTP. • Service planners at NFTA have to factor in the long-term sustainability of these systems and services vis-à-vis their budgets and priorities. • Since micro-transit on-demand service is new to NFTA, customer satisfaction, efficiency of the shuttle services need to be evaluated vis-à-vis other initiatives and approaches for transit services. • NFTA needs to work with their drivers, maintainers and personnel to make sure that system elements under their operations are not seen as an impediment to current programs and procedures.
City of Buffalo	• Staff need to be trained on the O&M and performance monitoring of the upgraded intersection. • Staff will need to develop standard specifications and templates for future intersection upgrades based on the proposed concepts. • Greater coordination between Middle Main construction teams and ITS4US teams is needed to ensure that streetscape improvements are coordinated and factored into the CTP system.
NYSDOT	• The program may create additional requirements and motivations for NYSDOT to maintain their open trip planner tools updated.
NYS DMV	• New policies and procedures for SDS operations may be established for the first time through this project.

Agency	Organizational Impact
Law Enforcement Entities	• New policies and procedures regarding SDS operations are expected to be established for the first time through this project.
BNMC Entities	• Transportation coordinators will have to assess their own services to see if they can gain efficiencies by leveraging the proposed system. For example, they may be able to reduce their safety fleet vehicles or operate them during different hours of the day to take advantage of the community shuttle.

7.3 Impacts During Development

The impacts anticipated to occur during development of the new system may include the following:

- Over the next several years, attitudes and regulations in NYS to autonomous vehicles may change. The SDS may achieve greater acceptance from the population and state regulation. These changes will provide a greater interest and curiosity to use self-driving vehicles.
- The project is estimated to take over five years across all three phases. This would impact relevant staff of the many partners and stakeholders as this would entail their involvement in meetings, studies, and stakeholder engagement about the program.
- There could be operational impacts to the leading agencies during testing of the proposed system.

7.3.1 Involvement of staff in meetings, studies, and stakeholder engagement about the program

Agencies listed in stakeholder list would need to be involved in regular meetings with the ITS4US system development team. Critical and upcoming milestones where significant staff participation is expected includes the following:

1. System Requirements.
2. National webinars and public meetings on this topic.
3. Integrated deployment planning meetings.

In addition, the ITS4US team and the project stakeholders will meet as necessary to continue refining the concepts and moving towards requirements definition.

Involvement of staff in meetings will peak around detailed design with many small multi-agency stakeholder meetings necessary to flesh out specific aspects of the proposed system.

7.3.2 User and support involvement

Involvement from travelers and community residents continues to grow beyond the initial engagement for the development of this document. In the near-term, user engagement activities will continue refining the ConOps, while moving towards requirements definition and integrated deployment plan.

In the development phase, a sample of users will be recruited as a testers and users of the prototypes of the system. These users will provide both the baseline data on current travel conditions as well as be early users of the CTP. These users will play an active role in prioritizing features and the determination of the roadmap for development.

7.3.3 Parallel operation of the new and existing systems

Since this system is not replacing an existing system, no significant parallel operations are expected. However, initial operations of the community shuttle are expected to use only human driven vehicles before adding SDS vehicles to the fleet.

7.3.4 Operational impacts during system testing

A few operational impacts during system testing are expected at this time but this list may grow with the development of the system.

1. Testing of intersection components may require close coordination with the City of Buffalo and local law enforcement to ensure that traffic control needs are not compromised.

2. SDS operations might require detailed roadway data collection that may be accomplished by specialized vehicles operating at slow speeds.

3. Shuttle operations during testing period may utilize temporary vehicles, stops and routes that may change over time to match up with demand and traveler preferences.

4. Temporary (but limited) sidewalk or bus shelter closures or obstructions may be necessary to install the smart signs.

5. Additional power and communication needs may be identified and accommodated during testing.

8 Analysis of the Proposed Systems

8.1 Analysis of the Proposed System

The proposed concept brings together inclusive design, integrated trip planning and micro transit elements to provide complete trip support to travelers who use the system. The system is intended to provide the following benefits to the stakeholders.

8.1.1 Travelers Using the System

Travelers using the complete trip system gain the following benefits from the system elements:

- A door-to-door travel planning app allows travelers with disabilities to make efficient transit trips to and from the deployment area.
- Turn-by-turn guidance that seamlessly provides wayfinding both indoors and outdoors near the BNMC.
- For those who are eligible for PAL, the system allows another way of accessing PAL services as well as providing more flexibility and support for trips that are not supported by PAL.
- Improved safety and ability to cross specific intersections and use specific prioritized pathways for accessing BNMC campus entities.
- Ability to access a new community shuttle service that connects the nearby neighborhoods to destinations and services within the zone of operations.
- Ability of caretakers to manage and monitor trips for the people they take care of.

8.1.2 Other Travelers

Even if not using the CTP or the system, travelers in the area benefit from:

- Improved information at bus shelters and outdoor wayfinding to BNMC campus entities through the TIH allows travelers to access their destinations better on campus.
- More timely notification of elevator and escalator outages through NFTA's existing traveler information channels.
- Integrated information on all of NFTA transit services available in Buffalo region.

8.1.3 BNMC Campus Entities

BNMC Campus entities benefit from the system by improving their customer experience and supporting the travel needs of their employees and visitors. Specific benefits due to the systems include:

- Improved access to health care including reduction in no-show numbers reported due to lack of transportation options for travelers.
- Intangible benefits from being seen as a model, inclusive and innovative campus in the region, such as increase potential to attract new medical entities, and BNMC partner funding to expand/initiate technology-oriented programs.
- Improved connectivity between the BNMC and the surrounding neighborhoods and growing the ability of the neighborhoods to access the facilities, services and transit options on campus.
- Ability to leverage the proposed system to optimize their own transportation services.

8.1.4 NFTA

NFTA sees the proposed system as a testable model that can leveraged for the rest of their service area. Specific benefits to NFTA include:

- Improved designs and templates for bus shelters that are based on universal design.
- A real-world test of self-driving shuttles in a micro transit service allows NFTA to understand the business models, the financial needs and the benefits of such services as part of their transit portfolio.
- Greater satisfaction among their riders, especially for persons with disabilities.

8.1.5 City of Buffalo

The city of Buffalo is uniquely positioned to leverage their ongoing activities around Main Street and enhancing their current plans with concepts proposed in this document. Specific benefits for the city include:

- Ability to extend intersection improvements by leveraging ITS4US concepts into planned construction for future designs.
- Replicable models for intersection design that can be used where conditions warrant in Buffalo.

8.2 Limitations and Disadvantages

The proposed system includes a few limitations:

1. The ability to generate accurate trip plans is limited by the availability of real-time data especially around sidewalks and transit services. In particular, if information about obstructions is not made available, trip plans may not be accurate.

2. The SDS operations is limited by the Operational Design Domain (ODD) of the service. The ODD may include specific environmental conditions that must be met. Current models of SDS do not allow operations under adverse weather which is a limitation in Buffalo.

3. The initial zone of operations for the community shuttle is limited for the scope of the deployment. Travelers, who are outside the zone, are not able to access the community shuttle.

4. The underlying physical infrastructure (although being improved in parallel) may limit the ability to create an accessible trip plan that meets traveler's preferences. For example, there might not be a pathway that is fully accessible for a particular origin and destination based on a traveler need.

5. Accessibility features of SDS vehicles may be limited since manufacturers are still figuring out the requirements.

6. CTP user interface-related accessibility needs are limited by current smartphone technologies and operating systems.

Disadvantages of the proposed system include:

1. Current lack of integration with private transportation modes and services (like taxis, non-emergency transportation providers, transportation network companies). This may be added in the future.

2. No fare payment built into the CTP. This also may be a feature that is considered in later versions.

3. Lack of centralized control and communication with intersections that minimize the opportunity for future transit and shuttle signal priority.

8.3 Alternatives and Trade-offs Considered

8.3.1 Shuttles Subsystem Trade-offs

In discussing the Concept of Operations for the Subsystem, the project initially considered a concept of operations involving a fleet of SDS to address the first- and last- mile segment of trips to- and from- BNMC. Specifically, the SDS fleet were to be designed to connect the metro stations and the bus stations serving the campus, to the entry points of the various BNMC buildings, thereby providing for a door-to-door, complete trip. In other words, the SDS fleet was envisioned to serve as a feeder/ distributor to the public transit system. Figure 16 shows the initially proposed route of the SDS fleet (drawn in blue).

The transit service type of the SDS fleet envisioned was somewhat akin to flexible transit routing. While the fleet was to generally follow the blue route, SDS were to be allowed to deviate slightly (for example for 0.25 miles) from its prescribed route to pick up or deliver riders to their final destinations. In addition, SDSs were to be allowed to skip stops based on the destinations of the riders and calls for service that it receives, in order to optimize operations and minimize unnecessary delays.

Figure 20. Initially Proposed SDS Service Routes
Source: Buffalo, NY ITS4US (Modified for Section 508 Compliance)

Following further discussions with user groups, project partners such as NFTA and BNMC, it was felt that a more pressing need was connecting the underserved neighborhoods, such as the Fruit Belt, to public transit and services, rather than just providing a circulator around the campus. With this understanding, the Concept of Operations was modified to that discussed in section 5.2.2.

In terms of the type of vehicles that will be autonomous, the project will explore two options. The first option will use a low-speed, electric SDS (examples include Olli which is manufactured by Local Motors, Navya shuttles, and EasyMile). A big advantage of SDS for the current project is that the vehicle design could be easily adapted to support accessibility particularly for people who use a wheelchair for example. Olli for example has a low floor, and ample space inside that would allow for having accessibility support mechanisms (e.g., a ramp, onboard the shuttle, that can be deployed to support PWDs to board the shuttle, or a wheelchair securement mechanism). The challenge of using SDS, however, for this project is that many of those shuttles have a joy-stick mechanism, as opposed to a traditional steering wheel, whereby the human steward can override the autonomous driving mode, and manually control the steering, as well as the speed of, the shuttle. As a result, the operations of such vehicles in the majority of states at the moment (including New York State), would require securing a waiver that would acknowledge the fact that the use of the joystick for manual control can be viewed as satisfying the Federal Motor Vehicle Safety Standards (FMVSS) related to the presence of the steering wheel.

The second option is to take an electric shuttle and or a traditional van (e.g., Ford Transit, Chrysler Pacifica, etc.) and allow autonomous driving. This allows for satisfying the regulatory requirements pertaining to the AV satisfying FMVSS, and the presence of a human driver behind the steering wheel of the AV to intervene during emergencies (this would be similar to the current operations of Waymo in Chandler for example). On the downside, however, the vehicle design may not be easily adaptable to help satisfy the accessibility needs of travelers on wheelchairs for example.

8.3.2 Transit Signal Priority and Fare Payment Integration

Two common transit related applications were considered initially but did not make the cut in terms of trade-offs for the system for different reasons.

The type of shuttle service being considered is not well-suited for transit signal priority since the goal of the service is not speed or reliability through a corridor. For the existing NFTA bus routes in the corridor, there are ongoing discussions about TSP that may be addressed outside this project.

For fare payment, NFTA-Metro is currently upgrading their fare payment systems and has the ability to pre-pay fares electronically through the Token Transit app. With Token transit and upcoming fare payment systems still new and maturing, the stakeholders did not feel that the proposed concepts need to include trip payment.

Appendix A. Technical Supporting Information

Safety and Reliability Public Acceptance Research for SDS

Safety and Reliability of Olli

The study tested the Olli self-driving shuttle on UB Proving Grounds for Connected, and Automated Vehicles (CAVs) located at UB North Campus in Amherst, NY. The version evaluated was a pre-commercial version of the shuttle, dubbed version 1.0. This was accomplished using a set of twelve testing scenarios designed for testing various aspects of Olli's driving behavior and maneuvering. Key findings regarding safety and reliability testing of Olli are summarized below (Shi, et al., 2021).

- Olli was able to follow a front vehicle driving ahead of it, and to maintain a desirable speed. It also maintained a desirable speed when there were vehicles following.
- Olli was able to complete left- and right-turning maneuvers safely and no manual intervention was needed. While making a turn, the shuttle was able to accurately, and in a timely fashion, detect any conflicting vehicle or obstruction ahead on its route and to stop by itself.
- Olli was able to cross a four-way intersection normally without conflicts. In addition, the shuttle would not pass the intersection if there were vehicles present at conflicting directional stop signs, even if those vehicles were stationary. Olli's version 1.0 did not seem to be applying the common traffic rule at four-way stops, which states that the vehicle that arrives first gets to go through the intersection first. Rather, Olli prioritizes safety and only moves when it perceives that there are no other conflicting vehicles at the intersection.
- Olli appears to successfully detect obstacles/pedestrian suddenly appearing in its path and to react in a safe manner by bringing the shuttle to a full stop. Moreover, Olli is not oversensitive and does not over-react to the presence of pedestrians on the sidewalk, as long as they are stationary or moving parallel to its path (hence no conflict).
- During the cases, when another vehicle overtook (i.e., passed) Olli, the shuttle generally maintained travel at its design speed. The only exception was when the human driven vehicle merged back in the original lane too early, leaving a space headway of less than approximately 12 meters (39 feet) between it and Olli. In that case, the shuttle would apply a sudden brake, to maintain safe distance, and then resume at a desirable or design speed.
- Olli managed to detect a stationary vehicle, located in front of a human-driven vehicle (i.e., Olli is the third vehicle in line in such a setup), after the human-driven vehicle had changed lanes. The shuttle stopped, in a reasonably smooth manner, to avoid collision.
- The perception and recognition algorithm used for Olli version 1.0, appears to be unable to distinguish between piles of snow located at the sides of the road, and a real hazard or

obstacle that it needs to avoid. Because of this, Olli stopped frequently when snow was piled to the side of the road (see Figure 21).

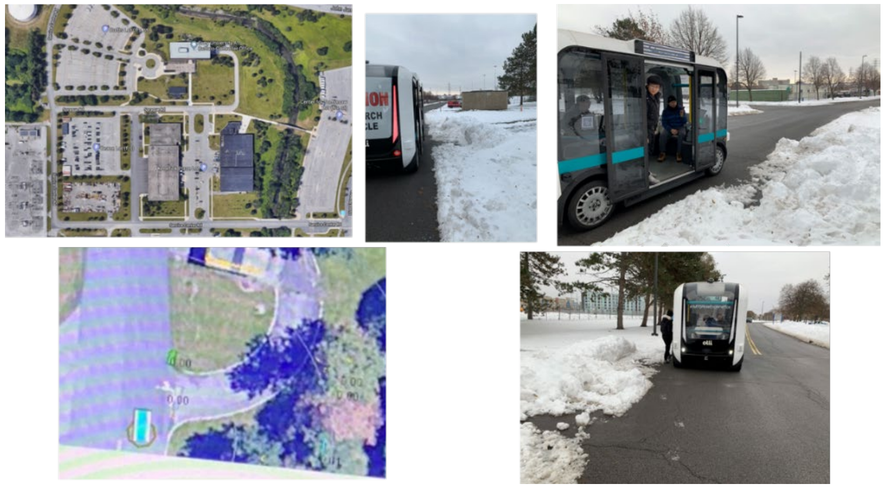


Figure 21. Olli's Stopping as a Result of the Presence of Snowbanks.
Source: University at Buffalo

Public Acceptance of Olli and AV Technology

The study also surveyed Olli's riders during the numerous demonstrations performed as a part of the study. The survey included a set of questions designed to solicit the views of riders regarding AV's safety, reliability, and adoption. Participants in the survey were asked to answer those questions twice, before riding Olli as well as after the ride. In addition to analyzing the results from the surveys completed by Olli's riders during the project, the research team leveraged two other AV-related surveys which were recently conducted in the Buffalo-Niagara region. The first survey was a 2016 web survey, open to the travelling public of the Western New York Region. The second survey was performed for a group who participated in an all-day forum, organized by the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) to learn more about autonomous mobility in August 2019. Some of the insights gained from analyzing those surveys are summarized below (Sadek, et al., 2021).

- About 39% of those surveyed stated that they would ride in an AV. In addition, 26% of the surveyed indicated that they would prefer an AV to a standard vehicle.
- A significant majority of those surveyed cited issues with control and liability, with many stating they would need to be able to take over control of the vehicle (85%), or be free of any legal (81%) or monetary (73%) consequences of an accident in an AV.
- Those who stated they understood the benefits of AVs were more likely to say they would ride in, own, and prefer an AV, while those who stated they enjoyed driving were less likely to agree with all three statements.
- Participants with longer commutes were more open to AV usage and unlikely to be concerned with liability, but also showed a need for optional manual control.
- Race, education, and type of employment were not found to have a significant impact on how individuals responded to any of these statements.

- Following the interactive experience with the SDS, Olli, participants were found to be more likely to agree with the statement: "I am confident that we will have fully AVs on the road in the near future."

Ongoing Accessibility Research

Over the past decade, the University at Buffalo (UB) team, particularly the IDEA Center, engaged in diverse accessibility research related to sidewalks and intersections, bus shelters, and wayfinding systems. Some, but not all, of this research took place in the city of Buffalo and with direct BNMC engagement.

Sidewalks/Intersections

Complete Streets

Since 2010, the IDEA Center at UB has engaged in research to explore the implementation of Complete Streets. Complete Streets (CS) policies strive to create streetscapes that support diverse transportation modes and users (Smart Growth America, 2018). CS encourages changes to planning efforts that balance the needs of pedestrians, bicyclists, public-transportation users, and motorists, regardless of age, ability, income, ethnicity, or mode of travel. Although more than 1,600 jurisdictions in the United States have adopted CS policies (Smart Growth America, 2020), including the City of Buffalo, limited research explores the implementation and evaluation of CS projects on a national scale. Furthermore, results from focused interviews (Lenker, Maisel, & Ranahan, 2016a) and an online survey (Ranahan, Maisel, & Lenker, 2019) conducted by UB team members indicated that jurisdictions with CS initiatives do not systematically collect data that demonstrate the impact of individual projects.

In response to this knowledge gap, the IDEA Center collaborated with GObike Buffalo on a NYSERDA grant (contract 46819) to evaluate the implementation of Complete Streets in the city of Buffalo. A field study deployed multiple data collection tools to capture a diversity of impacts, including: (a) streetscape quality; (b) street usability and satisfaction for drivers, bicyclists, and pedestrians; (c) traffic volume for vehicles, pedestrians, and bicyclists; (d) accidents and injuries; (e) economic vitality; and (f) health impact. These impact measures were focused on 8 street corridors where Complete Streets projects had been implemented or were planned throughout the city. These corridors were chosen because of their socioeconomic diversity, their mix of commercial and residential uses, and their range of Complete Streets features.

The survey responses from over 2,200 Buffalo residents, merchants, and streetscape users indicated that Buffalo’s Complete Streets projects were largely successful and very popular among all three stakeholder groups. When pre- and post-implementation volume counts for vehicles, pedestrians, and bicycles were available, the data indicated that Complete Streets corridors absorbed higher volumes of vehicles, pedestrians, and bicyclists and became safer in terms of total collisions and injuries. In terms of health impact, the self-reported data from all three survey groups indicated a positive and substantial increase in walking and biking behaviors, suggesting that Complete Streets corridors support and elicit healthy behaviors (Lenker, Maisel, & Ranahan, 2016b).

The team conducted a similar study, funded by the National Institute on Disability, Independent Living and Rehabilitation Research (NIDILRR) that compared a street corridor before and after it underwent significant street improvements aligned with CS in the Village of Williamsville, NY, a suburb of Buffalo. The Village planned a series of CS-related projects such as introducing traffic calming measures, enhancing intersections that facilitate pedestrian crossing with curb extensions, planting trees, and installing a new high-intensity activated crosswalk beacon (HAWK signal) for a mid-block crossing. The goal was to balance the needs of automobile drivers with those of pedestrians, bicyclists, and public transportation users while improving pedestrian safety and walkability. Survey results (pre, n=148 and post, n=100) indicated that streetscape users post CS implementation rated the street as significantly more satisfactory than the pre-construction survey participants; frequent walkers reported increased perceived safety and higher overall satisfaction. Post-construction participants were more likely to report there were sufficient crosswalks and pedestrian signals, as well as faster traffic speeds (Maisel et al. submitted).

Accessibility/ADA Audits

The ADA requires all covered entities to provide accessibility to all their buildings and sites, including parking. Title I of the ADA requires places of employment to provide accessibility for job interviews and access to work sites, although not the workstation itself. Title II applies to public entities and Title III to all public accommodations, including those that are privately owned.

Public rights of way must therefore comply with Title II of the ADA to ensure accessibility for people with disabilities. Property owners are responsible for maintaining an accessible path of travel from the public right of way (PROW) to their buildings under the ADA and to all amenities on their sites, e.g., gardens, site furniture, public art, parking garages, food stands, etc. The ADA has these basic requirements that pertain to the campus exterior environment: 1) a continuous accessible path of travel along sidewalks, 2) curb ramps where pedestrian access is needed to street level, for example, at street crossings, on-street parking and loading zones for vehicles, and 3) an accessible path of travel across streets at marked street crossings, and 4) accessible parking.

Accessibility issues on sidewalks include providing a reasonably level, slip resistant, smooth paths of travel to accommodate people who use wheeled mobility devices and walking aids and those who have difficulty maintaining balance and walking. The latter group includes people with prosthetic limbs, limitations of gait and loss of feeling in lower extremities. For legal purposes, all the walking surface conditions above are defined with detailed specifications, for example, the maximum running slope and cross slope of a walkway, the maximum height of changes in level in the surface, and the volume of sound produced by accessible pedestrian signals.

Staff of the IDEA Center have served as expert consultants on two class action ADA lawsuits against cities (San Francisco, CA and Los Angeles, CA), and more specific lawsuits against individual building owners whose properties abut PROW. Thus, the Center has an in-depth knowledge of the problems complying with the law and insight into how universal design could improve upon the minimum requirements of the ADA. Our experience indicates that the most common problems found along pedestrian pathways, both on PROW and on private property, include: 1) walkway surfaces that exceed minimum requirements for smoothness; 2) excessive running slopes and cross slopes; 3) overly steep curb ramps and counter slopes where the ramp meets the street; 4) lack of curb ramps at loading zones, including public transit stops; 5) lack of accessible parking or inadequate numbers of accessible parking spaces; 6) poorly signed accessible parking; and 7) discontinuity in accessible paths of travel that force people who need them to use longer routes to their destination.

Many intersections also lack accessible pedestrian signals, particularly important for pedestrians with visual impairments. One of the IDEA Center's industry partners, Touch Graphics, Inc., a company that also participated in the NYU study in Manhattan, which was mentioned in the proposal, has developed and tested several innovative technologies that could be employed, including tactile signs describing the traffic flows at pedestrian signal buttons and training and orientation tools for improving understanding of the environment (http://touchgraphics.com/portfolio/tactile-maps-and-guides/).

Cold Weather

Treacherous winter conditions pose safety challenges to people with disabilities. Pavement design and condition is a major source of slips and falls. Slippery sidewalks in winter are responsible for a large number of serious injuries and deaths each year. The accumulation of winter contaminants such as snow can potentially immobilize people in wheelchairs (Lindsay & Yantzi, 2014). Black ice, also known as glaze ice, appears completely clear to the eyes. This is a danger to people who are unaware of road surfaces. It is not hard to imagine that it can be more problematic for people with visual impairment (Lighthouse Guild, 2016). Such severe weather conditions form a barrier between the society and people with disabilities who are trying their best to engage in daily activities. Many individuals with disabilities, especially older adults, rarely leave home when the weather is cold, and almost never when the weather is snowy or icy (Row, Paul, & Fernie, 2004; Fernie, Row, Paul, & Maki, 2005). Therefore, it is imperative to ensure the safety of pedestrians, especially people with disabilities, in built urban environments.

As part of the Rehabilitation Engineering Research Center on Universal Design and the Built Environment, a project funded by NIDILRR and based at the IDEA Center, collaborators at the Toronto Rehab Institute studied the impact of cold weather on street crossing using video recordings at a busy Toronto intersection. They identified short street crossing times and pooling of water as snow and ice melt at the bottom of curb ramps as two major problems for pedestrian access (Li & Fernie, 2010; Li, Hsu, & Fernie, 2013).

Another major problem related to cold weather is deterioration of tactile warning signals (TWS), which are required on all curb ramps. The NYSDOT has installed TWS on parts of Main St. made by pressing molds into a concrete mixture. In the BNMC district, a different type of TWS has been used, a thin mat of a composite plastic material. However, all along Main St. and elsewhere, both these materials are deteriorating from salt and shearing of plow blades used to clear snow from sidewalks. Current standards designed to reduce slips and falls on TWS often lead to serious problems when cleaning ice and snow from the domes. In fact, some materials used for TWS are even more slippery than concrete pavement, presenting a dilemma in which safety devices designed for people with visual impairments actually may be reducing pedestrian safety for everyone.

In 2018, colleagues from the Toronto Rehab Institute conducted lab and field studies to investigate different types of pavements in terms of the coefficient of friction and snow/ice melt property. Despite the fact that heated pavement (HP) had high walkability in winter, the incurred cost from installation and operation got much steeper than pervious pavement (PP) or conventional pavement (CP) (Jung, Kaloush, & Way, 2002; Home Advisor, 2017; Low Impact Development Center, Inc., n.d.). PP was a much cheaper and reliable alterative that could improve the safety of sidewalks. As proved through lab experiments, PP possessed the physical characteristics and thermal properties, which accelerated the thawing of snow and ice after snowfalls or freezing rain. Using PP pavements not only reduced the runoff volume, but also reduced the risks of slips and falls. Therefore, it will help people with physical disabilities to walk safely and comfortably on the sidewalks cleared from ice and snow.

These studies reinforce the importance curb ramp and sidewalk maintenance in cold weather cities. The ADA and city ordinances require property owners to remove snow and ice promptly after snowfalls. However, in practice, there is very little enforcement of such rules and the burden on property owners is high in a city like Buffalo that receives large amounts of snow over a short period of time. Snow and ice are not only major barriers to accessibility, but they can also force pedestrians to enter and wait in the vehicular path of travel to avoid climbing over piles of snow. A local company, Engineered Plastics, has developed an effective snow and ice melting system that can keep sidewalks free of ice and snow. Using a paving material with less mass and higher conductivity than concrete, the technology can rapidly heat up when needed thus eliminating the need to remain in heating mode throughout the day. The technology has been proven effective in at least one location (a Chicago elevated rail station), but the company has not marketed this product extensively. Although the IDEA Center tried to engage the company in a test of the product, we were unsuccessful because we could not offer them any funding to pay for their engagement. Another approach to maintenance of sidewalks and curb ramps could utilize video surveillance and machine vision to identify problem sites, enforce existing policies by collecting evidence of violations, and generate early warning of dangerous conditions. We know of no applications like this.

Bus Shelters

Bus shelter are an important feature of transit systems, especially in cold weather cities. But most are poorly designed and often are underutilized because they are not well maintained and do not provide enough shelter from the weather. The IDEA Center has a history of research and design exploration of bus shelters. The Center served as consultants to Nelson Nygaard Associates on a project sponsored by Easter Seals Project Action. The Toolkit for the Assessment of Bus Stop Accessibility and Safety (https://www.nadtc.org/wp-content/uploads/NADTC-Toolkit-for-the-Assessment-of-Bus-Stop-Accessibility.pdf) is a compilation of research and best practices on bus stop design. It includes the ADA requirements that apply to bus stops and shelters and best practice solutions, including universal design strategies.

Two architecture design studios, taught by Edward Steinfeld, investigated innovative bus shelter design using universal design concepts. The studio studied bus shelter designs from around the world. Input to the studio was provided by a leading architectural firm, Grimshaw Associates, who designed the bus shelters deployed in New York City. Major cities like New York employ "franchise bid" programs to finance bus shelters and gain revenue through advertising. Cities develop specifications for the shelters and entertain bids from advertising companies to produce and maintain shelters over a long period of time. The companies hire leading design firms to design iconic bus shelters. They pay for the construction and maintenance of the shelters and obtain revenue from the sale of advertising space. The last franchise bid that New York ran is reaping the city $40 million in revenue each year.

Wayfinding

Useful wayfinding information is critical for supporting independent community mobility, an important aspect of quality of life (Karimi, Diaz, Pearlman, & Zimmerman, 2014). Finding one's destination inside buildings and on sites has always been a major source of complaints from visitors and even regular inhabitants. For people with disabilities, it is often impossible without assistance. A range of touch screen Transportation Information Hub (TIH) and “you are here” maps are typically utilized to assist with wayfinding in buildings and sites. These technologies often pose serious physical accessibility and interface usability issues for individuals with disabilities and the general public (Gao & Sun, 2015; Hagen & Sandnes, 2010; Harper, et al., 2019). Independent touch interaction is widely used to assist with accessing wayfinding information (Harper, et al., 2019).

To address wayfinding challenges, building owners and managers are commissioning multisensory maps and models that support tactile exploration. These devices are now available in museums, workplaces, schools for the blind, historic buildings, and other sites. They provide users with detailed information about their location and directions to nearby destinations. The most advanced of these were produced through research conducted at the IDEA Center (Landau, Subryan, & Steinfeld, 2014). Multisensory models provide more information and enhance usability for an expanded population, particularly individuals with vision impairments. Over the past 10 years, the IDEA Center has partnered with Touch Graphics, Inc. to create and evaluate universal designs for innovative wayfinding systems to overcome community mobility barriers frequently experienced by people with disabilities. Together, we developed an innovative process for producing multisensory interactive models of buildings and sites to improve wayfinding tasks for all users. Users can access information either through general exploration or structured searching using menus and a simple cursor (Landau, Subryan, & Steinfeld, 2014). Refreshable Braille can also be provided for the deaf/blind.

With early prototypes installed and evaluated at various schools for the blind, and more advanced installations at the Smithsonian Institution (see Figure 22) and the National Park Service’s Alcatraz Island Park, the highly visible ‘test bed’ models are now exposed to millions of people. Due to the generous support of a recent private donation, the next scheduled multisensory touch model installation is now planned for early 2022 at the Innovation Center on BNMC in early 2022.

Figure 22. Multisensory touch model installed at the Smithsonian Institution, Washington, DC.
Source: IDEA Center, University at Buffalo

Most general-purpose wayfinding systems are not customized for individual's specific needs. In particular, they do not recognize the presence of environmental barriers to people with disabilities. Khanuja (2019), a Masters student at UB, completed a thesis on wayfinding in urban areas with a focus on design for people with mild dementia. She proposed a system that would allow caregivers to develop customized route guidance for their care recipients and intervene via smart phone if a person encountered a difficulty. Such a system has a universal design application for a complex medical campus since most visitors are only going to one destination.

Appendix B. Physical Improvements to Support Buffalo ITS4US

Physical improvements to the infrastructure will occur through construction and improvement programs as discussed in Section 3.2.1.6. The path, facility and intersection information sources, wayfinding and improved accessibility features will be incorporated into the CTP routing algorithms with higher accessibility scores than ones that have not undergone improvement. The result will be to provide greater accessibility to travelers.

Physical Improvements to the Sidewalks

The following features will constitute the inclusive sidewalk components—see Table 26 for more information. These will not directly interface with the other aspects of the system.

- Marked accessible path. The clear width of the accessible path will be at least 60 in. wide. The path will be marked in a contrasting color that is easily perceived by those who need it and designed to keep obstacles like street furniture, parking meters, and garbage receptacles outside its boundaries.

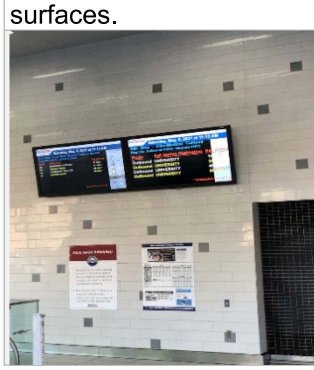
- Guide paths. To help clients and employees of VIA find crosswalks, the transit station and bus stops, a marked accessible path (both visual and tactile markings) will lead to these key destinations. Research on the efficacy of tactile tiles for guide paths is inconclusive. Further, we know that tactile domes, the standardized tactile warning specified in the ADA, can actually be more slippery than the concreate sidewalk surface itself. In cold weather cities, we know that tactile guide strips are often covered with snow and ice making them ineffective when needed the most. Over time, they can also be damaged by snow removal and ice melting chemicals. Placing them in the center of pathways also impedes the use of wheelchairs and interferes with walking. Thus, a different method will be sought to differentiate the edge of the accessible path without impeding walkability and wheel ability.

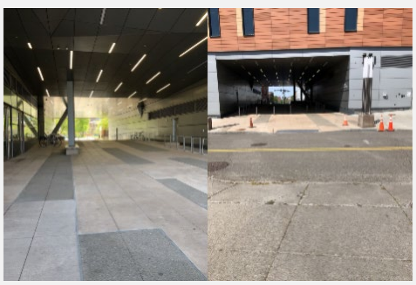
- Slip resistant surfaces. Finished concrete can be slippery, even when not covered with ice and snow. A textured surface will be identified to reduce slipperiness using a new testing method devised by an IDEA Center partner, the Toronto Rehabilitation Institute. Porous pavement will be explored as an alternative to traditional concrete paving.

- Accessible on-street parking. Accessible spaces closest to major destinations need to be reserved and signage and markings must be provided to reserve the space for those qualified. At both intersections, at least one accessible parking spot will be provided. This spot will include appropriate reserved parking signage for people with disabilities. The spots must be located to be as close as possible to the major destinations at the intersection, e.g., VIA, Oishei Children's Hospital and Buffalo General Hospital.

- The Main/Best intersection is the closest to a key partner, VIA. Signage will be added to the building façade to increase visibility. In addition, improvements will be made to the transit station real time information displays in order to enhance legibility.

Table 26. Planned Improvements to Sidewalks and External Wayfinding

Existing Infrastructure	Middle Main Sidewalk Improvements	Physical Infrastructure Improvement (not addressed by Middle Main)
 Sidewalks at Main/Best intersection lack guide paths and slip resistant surfaces.  Sidewalks from Main/Best intersection to VIA have steep cross slopes and uneven surfaces.	• New sidewalks on Main Street at Main/Best Intersection. • Curb cut ramps at intersection. • Accessible parking space along curbs near each intersection. • Accessible loading zones for shuttle services at Main/Best intersection.	• Use of new materials for sidewalks that minimize slipperiness. • New accessible guide paths to help clients and employees of VIA find crosswalks, the transit station and bus stop. • Curb cuts to accommodate community shuttle service. • Selection and initial testing of new accessible guide paths to help clients and employees of VIA find crosswalks, the transit station and bus stop. • Identification of textured to reduce slipperiness using a new testing method devised by an IDEA Center partner, the Toronto Rehabilitation Institute.
	• N/A	• N/A

Existing Infrastructure	Middle Main Sidewalk Improvements	Physical Infrastructure Improvement (not addressed by Middle Main)
Displays at Allen/Medical Station do not convey service information effectively.  Help Transportation Information Hub (TIH) at Allen/Medical Station lacks accessibility functions for those with visual impairments.  Outdoor wayfinding supports, including signage from Allen/Medical Station onto campus is lacking.		

Source: Photos courtesy of Victor Paquet, University at Buffalo

Intersection Improvements

Two intersections are targeted for improvement in coordination with this proposed project. Physical improvements to the signal systems and the crosswalks are needed. The crosswalk and approach to Main/Best are old and will be redesigned and rebuilt as part of the Middle Main project—see Table 27. The Ellicott/High crosswalk and approach were recently rebuilt. The crosswalk and signal system design at the former can include a full scope of issues while at the latter, will undergo incremental improvements.

Table 27. Planned Middle Main Improvements to Intersections

Existing Infrastructure	Planned Intersection Improvements via Middle Main Street Project
 Main/Best intersection lacks bump outs, crosswalk markings, and even surface.  Main/Best intersection lacks accessible pedestrian signaling.	• Installation of new intersections on Main Street, including Main/Best Intersection. • Installation of intersection features at Main/Best that enhance separation of bike lanes and pedestrian paths. • Installation of bicycle traffic signals at Main/Best that allow more control over traffic flow. • Installation of an accessible crossing signaling.

Source: Photos courtesy of Victor Paquet, University at Buffalo

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