Phase 1 Enabling Technology Readiness Assessment

ARC ITS4US Deployment Project

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<tr><td colspan="5">16. Abstract
The Atlanta Regional Commission Complete Trip - ITS4US Deployment project, Safe Trips in a Connected Transportation Network (ST-CTN), is leveraging innovative solutions, existing deployments, and collaboration to make a positive impact using transportation technology to support safety, mobility, sustainability, and accessibility. The ST-CTN concept is comprised of an integrated set of advanced transportation technology solutions (connected vehicle, transit signal priority, machine learning, predictive analytics) to support safe and complete trips, with a focus on accessibility for those with disabilities, aging adults, and those with limited English proficiency.

This document provides a technology readiness assessment of the technologies that are considered and proposed for the ST-CTN project. The assessment contains an inventory of enabling technologies, their technology readiness level and risks associated with the enabling technologies.</td></tr>
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Name	Date	Version	Summary of Changes	Approver
EMT / Subsystem Developers	August 25, 2021	0.1	Initial Draft	JD Schneeberger
EMT / Subsystem Developers	August 27, 2021	0.2	Initial Draft	Maria Roell
EMT	15 November 2021	1.0	Final	Maria Roell

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1. Introduction

The Enabling Technology Readiness Assessment (ETRA) document identifies and assesses the maturation of the enabling technologies (ET) used to deploy Atlanta Regional Commission's (ARC) Safe Trips in a Connected Transportation Network (ST-CTN) project.

Building from material in the Concept of Operations (ConOps) this document identifies ETs that will be used and leveraged to meet the user needs and future system requirements. Each technology identified in this document is assigned a maturity rating which describes whether the technology is available off-the-shelf, may be modified from existing / deployed technologies or products, or require additional research and development. Enabling technologies for each subsystem and the overall proposed ST-CTN system are described.

1.1. Intended Audience

The intended audience of this ETRA includes the stakeholders who will use, develop, and manage the software and infrastructure that will be deployed as a part of the ST-CTN system. That audience includes the ARC ITS4US team, the United States Department of Transportation (USDOT), and its Independent Evaluator. The ST-CTN project team includes the following partners and their respective roles on the project:

- **ARC.** Project management, concept development, and concept collaboration lead
- **Gwinnett County Department of Transportation (GCDOT).** System development and local agency deployment lead
- **Gwinnett County Transit (GCT).** System development and local agency deployment lead
- **Atlanta-Region Transit Link Authority (ATL).** Atlanta-Region Rider Information and Data Evaluation System (ATL RIDES) integration lead
- **Statewide Independent Living Council of Georgia (SILCGA).** Community coordinator lead
- **Georgia Department of Transportation (GDOT).** CV integration lead
- **Georgia Institute of Technology (GA Tech).** Technical innovation lead
- **GO Systems and Solutions (GOSystems).** System development lead
- **IBI Group.** ATL RIDES system and mobility application development lead
- **Kimley-Horn and Associates, Inc. (KHA).** Concept development and production management leads

In addition, this document will be shared with constituent agencies and stakeholders of related projects currently under deployment in the region who may be included in future ST-CTN system expansion.

1.2. Project Background

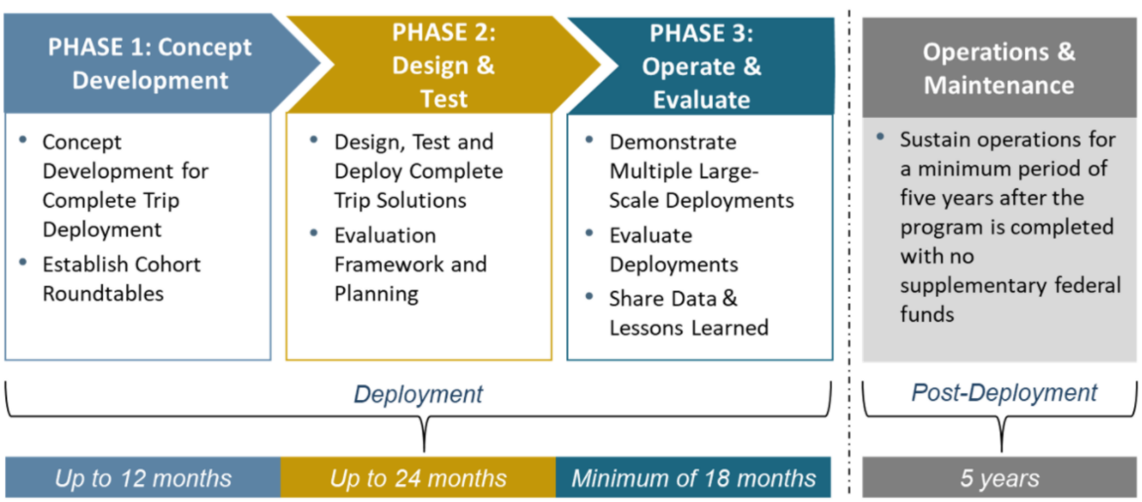
The Complete Trip - ITS4US Deployment Program is a multimodal effort – led by the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) – and supported by the Office of the Secretary (OST), Federal Highway Administration (FHWA), and Federal Transit Administration (FTA) – to identify ways 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 physical or cognitive disabilities, older adults, low-income individuals, and travelers with limited English proficiency (LEP). This program seeks to enable communities to build local partnerships, develop and deploy integrated and replicable mobility solutions to achieve complete trips for all travelers.

1.2.1. Project Phases

The Complete Trip – ITS4US Deployment Program will be executed in three phases. As depicted in **Figure 1**, deployment sites are expected to go through three phases:

- **Phase 1.** Concept Development
- **Phase 2.** Design and Testing
- **Phase 3.** Operations and Evaluation

Post deployment, sites are expected to sustain operations for a minimum period of five years without supplementary federal funds.



Source: USDOT, 2020

Figure 1. Phases of the Complete Trip – ITS4US Deployment Program

1.2.2. Project Complete Trip Focus

ARC was selected by USDOT as one of the Phase 1 projects to showcase innovative business partnerships, technologies, and practices that promote independent mobility for all travelers regardless of location, income, or disability. The project team intends to address multiple aspects of the Complete Trip by integrating multiple technological innovations. The ST-CTN system will integrate connected vehicle (CV) data with an open-sourced web-based and mobile application. The application will provide users with the ability to create a personalized trip plan with information regarding the navigation of physical infrastructure, the ability to resolve unexpected obstacles, and ensure users visibility to vehicle operators throughout the trip. The proposed deployment will provide targeted users with the ability to dynamically plan and navigate trips. Underserved communities of interest include:

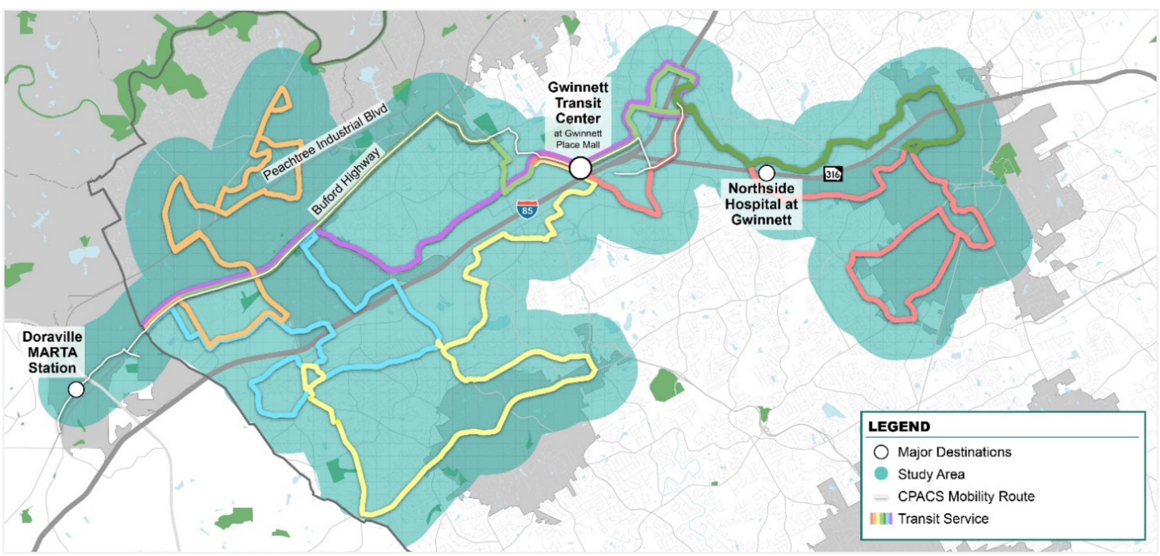
- **People with Physical Disabilities**. People with physical disabilities are limited in independent, purposeful physical movement of the body, or one or more extremities, and are substantially limited in one or more major life activity.
- **People with Cognitive Disabilities.** People with cognitive disabilities have a condition that makes it more difficult to interact or participate in the environment around them. Cognitive disabilities may affect a person's thinking, remembering, learning, communicating, mental health, sensory processing, or social interactions.
- **Aging Adults**. Aging adults may have trouble performing specific tasks within a set time period (e.g., crossing a road or boarding a transit vehicle), standing for an extended period of time, or may be more sensitive to weather conditions. Aging adults are people (typically 60 years of age or older) who have physical or cognitive limitations that impact their ability to perform daily activities.
- **Limited English Proficiency (LEP) Communities.** A person with LEP refers to a person who is not fluent in the English language. Users with LEP may have trouble understanding directions and alerts when delivered in their non-native language, may have different cultural norms that make it difficult to follow directions others would feel are standard, or may have difficulty understanding wayfinding signs.
- **Low Income Communities.** Users who fall into the low-income category may be single or no-vehicle households, may have trouble accessing different forms of technology (i.e., cellphone or personal computer), may be on reduced payment or fixed payment transit plans, may be unbanked (e.g., not have access to a bank account or credit card), or may use transit as their sole means of transportation. A person who has low income has a median household income that is at or below the Department of Health and Human Services poverty guidelines. Poverty guidelines designate $26,500 as the threshold for a household of four in the state of Georgia in 2021.

Table 1 below describes the demographics of each of these populations in the project area as a whole and in relation to Gwinnett County according to the 2017 American Community Survey. However, it must be noted that these populations are not mutually exclusive as many individuals are members of multiple of the below communities.

Table 1. Project Area Demographics

Population Type	Project Site Population	% Pop in Project Site	Gwinnett County Population	% Gwinnett Pop. in Project Site
People with Disabilities (non-institutional)	16,802	6.0%	32,032	52.5%
Aging Adults (Age 65+)	19,435	7.0%	78,898	24.6%
LEP Households	14,098	15.1%	24,069	58.6%
Low-Income (Individual Poverty)	53,223	19.1%	107,267	49.6%

The ST-CTN project will be implemented in Gwinnett County, which was chosen partially due to its representative nature. It faces many of the same challenges as much of Metro Atlanta, including suburban land-uses; wide, high-speed roadways; and inconsistent pedestrian infrastructure. This area also was chosen to leverage its implementation readiness and the CV planning work recently completed. A map of the project area can be found in **Figure 2**.



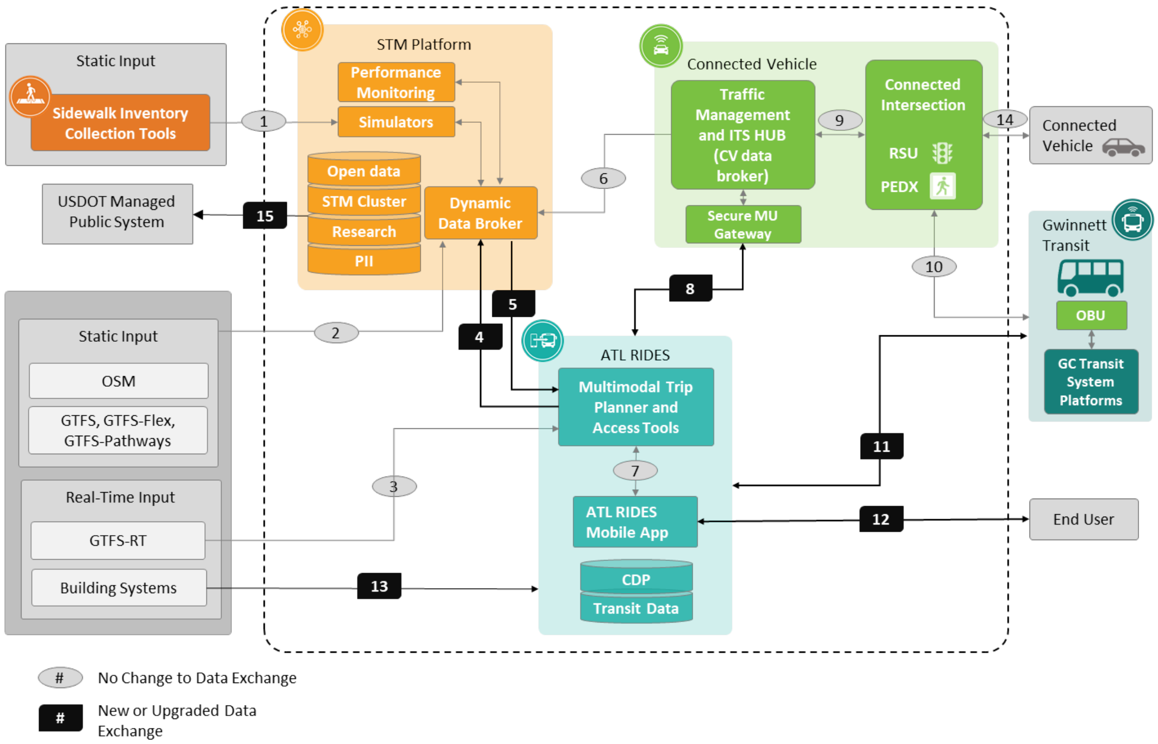
Source: ARC, 2020

Figure 2. ST-CTN Deployment Site Map

1.2.3. System Overview

The ST-CTN can be thought of as a *system of systems*; the scope of work required to develop, design, and deploy ST-CTN is focused on the expansion or enhancement of current systems and added connectivity between those systems. **Figure 3** provides a context diagram of the proposed system – indicating the system of interest and added subsystem connectivity. Each subsystem is indicated by color and icon: Sidewalk Inventory Collection Tools is burnt orange; Space Time

Memory (STM) Platform is peach; CV is green; Atlanta-Region Rider Information and Data Evaluation System (ATL RIDES) is turquoise; and GCT is teal. The STM Platform, ATL RIDES, and CV subsystems will each require expanded capability and added connectivity to support the proposed ST-CTN system. The Sidewalk Inventory Collection Tools and GCT existing independent systems will serve to support the proposed ST-CTN system. Data exchanges between subsystems are denoted by a gray or black line. A gray line indicates an existing and unchanged data exchange between subsystems. A black line indicates a new or upgraded data exchange between subsystems.



Source: ARC, 2021

Figure 3. ST-CTN Network Data Exchange Flow Diagram

Critical ST-CTN data exchanges are identified by number in the context diagram above and described in **Table 2**. The grey oval labels indicate existing data exchanges that will be utilized with no change to the current data exchange. Black rectangular labels indicate data exchanges that will be new or upgraded to support the ST-CTN system.

Table 2. Critical ST-CTN Connection Descriptions

Data Exchange ID	Description
1	Sidewalk inventory data, including accessibility features to the STM Platform simulators
2	Static and dynamic data from various existing sources to the STM Platform dynamic data broker

Data Exchange ID	Description
3	Static and dynamic data from various existing sources to the ATL RIDES multimodal trip planner and access tools
4	Mobile App logs, crowdsource asset condition data, and trip feedback
5	STM Network Impedance API
6	CV and Traffic Operations Messages: signal phasing and timing (SPaT), MapData (MAP), CV Advanced Traveler Information System (ATIS) broadcast data, NaviGAtor ITS, road characteristics, traffic data
7	Open Trip Planner (OTP) APIs and ATL RIDES APIs
8	Mobile Accessible Pedestrian Signal System (PED-SIG) / personal safety message (PSM)
9	CV messages
10	Transit signal priority (TSP) and other CV application messages
11	CV application transactions for transit applications including transit stop request (TSR)
12	ATL RIDES and Traveler exchange – profile, trip plan, settings, notifications, feedback, etc.
13	Static and dynamic information from building facilities to the ATL RIDES
14	CV data
15	Project data for USDOT-managed Public System

The subsystem functionality and data exchange technologies will be implemented by existing projects and augmented to ensure interoperability among the projects. The systems that compose the ST-CTN project are in different states of deployment. The CV subsystem is composed of mature traffic operations and situational awareness tools (NaviGator and MaxTime), Regional Connected Vehicle Infrastructure Deployment Program (CV1K) infrastructure (ITS Hub, generation of MAP and SPaT datasets, collection of basic safety message (BSM)). The ATL RIDES will be fully operational by the end of 2021 using an open architecture which includes a data broker to easily integrate with third party systems such as the STM, CV, GCT and call center application programming interfaces (API). The STM has been proven in several pilots which will be integrated together as part of this project. Each subsystem, component and data exchange that has yet to be integrated or is not recognized as a “mature” technology is described in this document.

1.3. Scope

The ETRA document identifies and assesses the technologies that contribute to building a solution to meet the ARC ST-CTN project goals, objectives, user needs, and system requirements. High level concepts for addressing end-user needs were described in the ConOps. The ConOps identified the system of interest including subsystems, their components, constraints, and operational and support environments, and their mapping to system needs. These components will drive the technologies needed to address system requirements as well as build and deploy the system solutions. This document decomposes the subsystems and their components into the most promising ET elements and addresses their readiness to deploy including risks and potential mitigation plans for high impact risks.

1.3.1. Document Overview

The ETRA provides documentation of the ST-CTN subsystem ETs and an assessment of each component's technology readiness and potential risk. The remainder of this document consists of the following sections and content:

- **Section 2** (Enabling Technologies Identification) identifies the technology readiness framework used for this project and the technologies that will be utilized to meet user and system needs that were defined in the ConOps and the system requirements that will be defined in the System Requirements Specifications (SyRS) document.
- **Section 3** (Technology Readiness Level (TRL)) uses the technology readiness framework described in **Section 2** to evaluate the technologies based on technology maturation and TRL scale.
- **Section 4** (Risk Assessment) documents the risks associated with the technologies that will be utilized for the project. The risks are evaluated according to potential impact and mitigation measures are identified.

1.3.2. Related Tasks

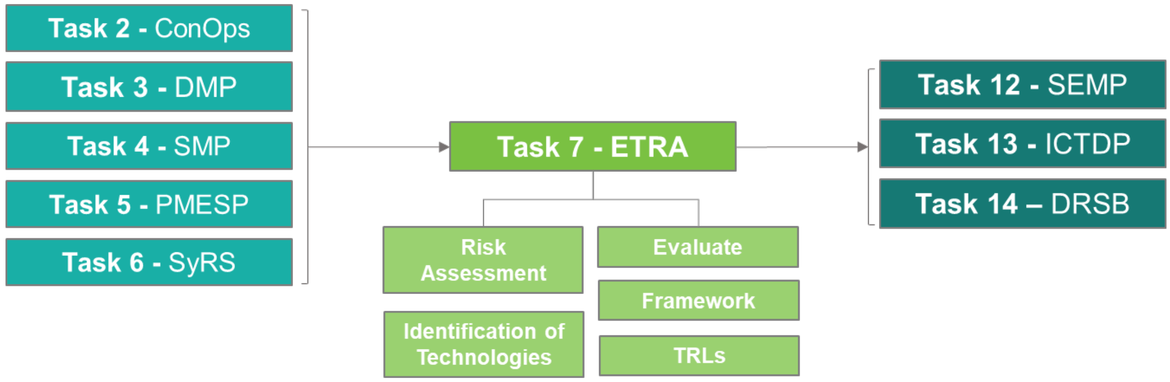
Table 3 provides a summary of the ETs related interactions within the planned deployment and key task areas that provide supporting information or will be guided by the ETRA.

Table 3. ETRA Related Project Tasks

Related Task	Summary
Task 2 – Concept of Operations (ConOps)	The ConOps is an input for the ETRA. The user group needs and use cases were defined. These user needs and use cases will ultimately be used in the later stages of the systems engineering process to determine the technologies.
Task 3 – Data Management Plan (DMP)	The DMP is an input for the ETRA. Data collection streams from the DMP are used to identify ETs and then are further used to develop and evaluate those ETs.

Related Task	Summary
Task 4 – Safety Management Plan (SMP)	The safety needs in the SMP are used in the ETRA to drive the requirements and technologies needed for project deployment. The safety needs were derived from the user needs and system needs of the ConOps.
Task 5 – Performance Measurement and Evaluation Support Plan (PMESP)	The performance measures of the PMESP will be used to determine the success of the ETs.
Task 6 – Deployment System Requirements (SyRS)	The SyRS, once complete, will also be an input for the ETRA. The user needs and system needs drive the system requirements. The system requirements are used in the ETRA to determine the technologies needed to satisfy user needs, systems needs and system requirements.
Task 12 – Systems Engineering Management Plan (SEMP)	The ETRA will be used to develop the SEMP in terms of standards, approaches, and models. The ETRA will provide insight into the technologies needed for implementation and help develop a management plan for deployment.
Task 13 – Integrated Complete Trip Deployment Plan (ICTDP)	Content from the ETRA will be used to inform challenges that need to be addressed through the deployment plan. The ETRA will identify technologies needed for deployment, risks associated with those technologies and their mitigation measures.
Task 14 – Deployment Readiness Summary Briefing (DRSB)	Information from the ETRA will be used to demonstrate the project's readiness for deployment in order to begin the Design/Build/Test Phase.

Figure 4 illustrates the key elements and interactions between the ETRA and related project tasks.



Source: ARC, 2021

Figure 4. ETRA Related Tasks

The ETRA document will guide future systems engineering documents and processes during the design and deployment phase.

1.3.3. Goals and Objectives

The vison of the ST-CTN system is to leverage existing advanced transportation technology solutions to support safe, reliable, accessible, complete trips for all, particularly undeserved communities, including people with disabilities, aging adults, people with LEP, and low-income travelers. To demonstrate the effectiveness of the ST-CTN project, well defined goals and objectives have been established to evaluate the success of the project against key performance measures and targets.

Goals and associated objectives for the ST-CTN project were defined based on the user needs identified during the development of the ConOps. These user needs include end user needs, infrastructure owner/operator (IOO) needs, and system needs. The goals and objectives clearly establish the intent of the project, guiding the system requirement and ET development. The success of the project will be determined based on the ability of the deployment to achieve the goals and objectives. The ETRA assesses those ETs that are envisioned to support the deployment of the ST-CTN system to achieve the established goals and objectives.

1.4. References and Applicable Documents

This document references the documents listed in **Table 4**.

Table 4. References

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ID	Referenced Documents
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[AVL]	The World Bank. Automatic Vehicle Location. Washington D.C.: The World Bank. (2011).

2. Enabling Technologies Identification

This section defines the technology readiness framework used to identify and assess the ST-CTN ET inventory. It also includes an inventory of the ETs for the ST-CTN project that will be assessed in **Section 3**.

2.1. Technology Readiness Framework

The Technology Readiness Framework applied to rank the readiness of technologies is based on ISO 16290 Space Systems — Definition of the Technology Readiness Levels (TRLs) and the FHWA Technology Readiness Level Guidebook [TRLG].

In this adapted framework, the process begins with inventorying the system ETs. Since the ST-CTN is composed of several existing systems that interoperate, the existing, deployed technologies are grouped into “core” capabilities and the new features, equipment, and interfaces are enumerated as separate ET elements. The process was iterative, in that when decomposing the elements, if the maturity of similar elements could be ranked at different maturity levels, they were separated into two elements. Similarly, if related elements (e.g., collecting preferences and forwarding notifications) were of a similar maturity, then they were grouped together. Mature technologies were not included in the inventory list, for example, traffic signal controller and TSP are mature technologies using formal consensus-based standards and testing protocols and deployed in hundreds of systems in the United States.

Key stakeholders were involved in discussing the ET inventory, readiness level and risks. Key system stakeholders – **System Developers** and **Infrastructure Owners and Operators** – identified the inventory elements, scanned the literature verifying technology efficacy and user acceptance, and reviewed pilot and proof of concept demonstrations to rank the technology readiness and understand the risks to deployment. The ET TRL assessment was conducted by each subsystem team lead and presented to the technical team for review and discussion. Although many of the ET items have been implemented, piloted, and demonstrated in the project operational environment, their integration may be new or less mature. A number of considerations were discussed that drove the inclusion in the ET inventory. They include:

- Current state of deployment of subsystem components in the region by stakeholder IOOs.
- Existing deployments and integration of technologies by project system developers in other regions.
- Existing deployment / pilots and integration of technologies and application in other projects (by other developers and IOOs).

- Studies and demonstrations of technologies considered for this project and their integration and interoperability in the system of interest.

The risks identified by the ET inventory will be integrated into the Project Risk Registry described in the project PMP, continuously monitored and updated throughout the course of the project, and contribute to allocating sufficient resources to ensure design, development, testing, and implementation resources during Phases 2 and 3.

The ET inventory related integration and procurement options, and associated needs and requirements are described in **Section 2.2**, the TRL rating is provided and justified against the [TRLG] TRL criteria (see **Table 5**), and the risks associated with most ETs are described along with mitigation approaches in **Section 4**.

2.2. Enabling Technologies Inventory

The ET inventory items listed in this section are derived from the ConOps functions and technologies including system concept, subsystem, component, constraints, operational environment and support environment technologies. Since the ST-CTN concept will be built on existing systems, an item only refers to a new or extension of the existing system which is not technically mature. Those interfaces that are not included within this inventory are deemed mature and do not require review. Each ET inventory item is described by the following subsections:

- **Subsystem(s):** The subsystem(s) which employs the technology. For interfaces, two subsystems are included. For a system-wide technology, the entry will include "system."
- **Description:** Detailed description of the technology and how it will be used by the subsystem or function. The description identifies what is currently implemented and how the new feature or technology will be leveraged by the ST-CTN concept.
- **Integration:** Description of the integration approach and characteristics needed to integrate the technology into the existing subsystem.
- **Procurement:** Description of the approach that will be used to procure, develop or acquire the technology and integrate it into the deployed system.

In addition, the technologies are mapped to the system needs as described in the ConOps and the system requirements listed in the SyRS. At the time of the publication of this document, the system requirements were still a work in progress. Related requirements will be mapped to each ET once the SyRS is approved for Phase 1 publication.

2.2.1. ET-1 Secure Mobile Unit Gateway (SMUG)

Subsystem: CV and ATL RIDES Subsystems

Description: The Secure Mobility Unit Gateway (SMUG) will serve as a secure means of exchanging information between a mobile unit (MU) (or proxy such as the ATL RIDES subsystem) and the CV subsystem. The SMUG serves to provide authenticated access, validate messages, and transform and direct the messages to the appropriate destination. In addition, it serves to respond to messages as appropriate. In summary, the Secure MU Gateway acts as a gatekeeper of Advanced Traffic Management System (ATMS), MaxView and MaxTime messages, and CV broadcast messages generated by the CV subsystem.

The SMUG serves a secure router with proxy server firewall capability. The security provision will enforce end-point authentication and restrict/validate pre-defined message sets.

Integration: The SMUG will sit between the CV subsystem and the ATL RIDES subsystem. The initial implementation will be between the ATL RIDES Multimodal Trip Planner and Access Tools (see Figure 3). The Data Exchange #8 will support message exchanges for several applications including ATIS and PED-SIG as described in Connected Vehicle Technology Master Plan (CVTMP). Most of these applications are supported by use cases, requirements and messages described in NTCIP 1211, 1202 and 1201 for the PED-SIG or SAE J2735 for the ATIS broadcasts, MAP and SPaT data.

Procurement: The technology will be acquired or repurposed from existing GDOT/GC Transportation infrastructure. The SMUG requires typical configuration to enforce the rules that meet the ATMS security policies which will be coordinated between GDOT/GC and ATL RIDES application developers. It will also need to scale to the number of users and applications that are deployed during the project time period.

Traceability: The following system needs and requirements are supported by ET-1.

- **System Need(s):** The primary system need is:
    - **CV-SY-5.1** "The system needs to connect travelers to the connected infrastructure to increase safety."
    - All the CV related needs in the User Needs and IOO Needs (see correspondence in ConOps) require that the traveler connect to the CV infrastructure. Due to constraints on communications and security technologies, a gateway will be implemented to implement a center-to-center interface. This is conceptualized as the SMUG.
- **System Requirement(s):**
    - 5.1.0-138 The SMUG shall process multiple message transactions simultaneously. The maximum number of simultaneous transactions will be identified during Phase 2 of the ST-CTN project. The quantity used for the pilot may not be the volume required for a fully operational system.
    - 5.1.0-142 The SMUG shall meet agreed upon security procedure, policies and protocols to authenticate, validate and restrict traffic between ATL RIDES and CV (and downstream signal controllers). The security procedures will be developed during Phase 2 of the ST-CTN project.

2.2.2. ET-2: CV and Traffic Data Feeds (Exchange #6)

Subsystems: CV and STM

Description: The published data is provided by the CV subsystem (from the Traffic Management and ITS HUB as identified in **Figure 3**) to the STM subsystem (Dynamic Data Broker). Data will include ATIS datasets (initially, the messages will include highway rail crossing alerts, emergency preemption locations), BSM, SPaT data and MAP data. The data will include both static (e.g., MAP) and dynamic data published at a 10 Hz rate. The data is currently available to other systems using a publish and subscribe (P&S) model from the current ITS HUB server. Additional functionality and datasets will be available from a new NaviGAtor deployment. This new system will be deployed sometime in the middle of the ST-CTN development process with both new and legacy data formats. The STM currently pulls the NaviGAtor data and will be updated to allow for subscription to these datasets as part of the ST-CTN deployment.

This ET is merged with ET-6.

2.2.3. ET-3 Mobile Accessible Pedestrian Application (PED-SIG)

Subsystems: CV and ATL RIDES (Exchange #8)

Description: The PED-SIG application allows for an automated call via the SMUG from the smart phone of an authorized pedestrian using the ATL RIDES mobile app (or MU) to the traffic signal, as well as audio cues to safely navigate the crosswalk. The PED-SIG scenario enables a traveler using a MU to request pedestrian signal actuation and exchange a message transaction set encapsulated by Exchange #8. The MU requires authentication and security credentials to signal a hands-free request through a SMUG (Exchange # 8). The ATL RIDES central system acts as a proxy to issue the request with information including crosswalk reference and signal phase requested. The data information will be facilitated by the phase data transmitted via NTCIP signal controller messages (NTCIP 1202/1201). After which ATL RIDES generates a signal request message (prgPriorityRequest). The signal controller (via MaxTime/View) will respond (via the SMUG) to confirm receipt of the request through the signal control status message (prsPriorityStatus). ATL RIDES will monitor the signal control status to provide information on the time until the crosswalk signal starts the walk phase and the time until the signal is toggled to the don’t walk phase. ATL RIDES will also update the signal controller with information on the pedestrian’s intention to cancel or clear the intersection based on their geolocation.

Integration: The ATL RIDES will need to implement the message exchange procedures and communications with the ATL RIDES mobile app. The interface exchange will be facilitated by ATL RIDES (ET-17) and processed by the SMUG (ET-1).

Procurement: The CV subsystem may need to be modified to incorporate the operational performance of the ATL RIDES data exchange. Additional logic will need to be programmed for the CV subsystem to ensure a trusted, secure interface (via the SMUG) between the ATL RIDES and signal control system (MaxTime/View and signal controllers) to exchange real time phase data prior to and during execution of the intersection crossing, and to provide the ATL RIDES with signal crossing locations and characteristics (for trip planning purposes).

The ATL RIDES software will need to be modified to support the processing performance (for tracking and geofencing), message exchange processing and logical processes to communicate signal states to the ATL RIDES mobile app.

Traceability: The following system needs and requirements are supported by ET-3.

- **System Need(s):** The primary system need is:
    - **IC-SY-4.1** “The system needs to connect to traffic signal system infrastructure to enable travelers to activate crosswalk signals using a hands-free method, or automatically using their trip plan and location so that the traveler is able to complete their trip based on their preferences and abilities.”

  - Additional Needs that apply include **IC-SY-4.2** and **CV-SY-5.1.2** (included in Appendix C).
- **System Requirement(s):**
  - Requirements related to IC-SY-4.1 and CV-SY-5.1.2 include 4.1.0-111 through 4.1.0-127.
  - Requirements related to IC-SY-4.2 include 4.2.0-135 and 4.3.0-136.

2.2.4. ET-4 Transit Pedestrian Indication (TPI)

Subsystems: CV and ATL RIDES

Description: The TPI application provides vehicle-to-device communications to inform pedestrians at a station or stop about the presence of a transit vehicle. This application also informs the transit vehicle operator about the presence of pedestrians nearby and those waiting for the bus. It helps prevent collisions between transit vehicles and pedestrians. ATL RIDES will broker the information for the pedestrian to provide subscription information about the presence of the vehicle approaching the transit stop. ATL RIDES will alert the vehicle that a traveler is waiting at the transit stop. These alerts directed to travelers using the ATL RIDES app (or through other communication channels) are already implemented as notifications in the current system. The flow from the pedestrian (with the ATL RIDES mobile app) traverses Exchange #12 to #8 through the CV subsystem (Exchange #9) to transit vehicles (Exchange #10). The flow to alert the traveler traverses the reverse order. There are no existing CV use cases, requirements, or message sets that conform to the needs of this data exchange. The PSM sent by a MU (e.g., mobile phone) alerts vehicles to the presence of pedestrian, but there is no message that alerts the transit operator that a passenger is waiting for a pickup; (the intention is not included in the PSM).

This ET is merged with ET-5.

2.2.5. ET-5 Transit Connection Protection (aka Transit Stop Request (TSR))

Subsystems: ATL RIDES and GCT (Exchange #11)

Description: The Transit Connection Protection application allows a transit passenger to send a request to an approaching transit vehicle requesting a pickup at a specific stop. This application allows a transit vehicle to know that a passenger has requested a transit stop from the ATL RIDES mobile app. The mobile app will track the traveler and notify ATL RIDES that the traveler is near their bus stop. When the traveler is a configurable time from reaching their stop, ATL RIDES will alert the operator through the GCT computer aided dispatch (CAD) interface that the traveler requests pickup at the bus stop of a specific route / route direction to a specific destination.

Integration: The GCT CAD system will integrate a modified Transfer Connection Protection algorithm to allow ATL RIDES to request a connection for a traveler waiting or approaching a GCT bus stop. The system will be implemented by an API provisioned by the CAD system that ATL RIDES will use. Methods and messages that alert the operator to protect traveler connections exist in the CAD system used by GCT.

Procurement: Modification to existing software in the GCT CAD system will be needed to generate an API used by ATL RIDES to inform the system to manage the traveler's connection.

Traceability: The following system needs and requirements are supported by ET-5.

- **System Need:** The primary system need is:
    - **TT-SY-3.1** "The system needs to provide a method for a traveler to send a stop request to an approaching transit vehicle. The stop request may also identify special needs of the traveler."
    - Additional needs to support the Transit Connection Protection application include **TT-SY-3.2** (see Appendix C).
- **System Requirement(s):**
    - Requirements related to TT-SY-3.1 include 3.1.0-092, 3.1.0-093, 3.1.0-095 and 3.1.0-096.
    - Requirements related to TT-SY-3.2 include 3.2.0-105.

2.2.6. ET-6 Transit Next Stop Request (in vehicle)

Subsystems: ATL RIDES and GCT (Exchange #11)

Description: The Transit Next Stop Request allows a transit passenger (traveler) to use their ATL RIDES mobile app to perform a hands-free actuation of the next stop request. This application actuates the Next Stop indicator in the bus. The ATL RIDES mobile app will track the traveler generate a notification to the bus Next Stop request service. When the bus begins to move from the stop prior to alighting, the mobile app will trigger the request.

Integration: The next stop request requires that ATL RIDES can send a message to the bus system and actuate the Next Stop Request. A wireless relay is needed to connect to the vehicle next stop request controls. Each manufacturer system is proprietary and unique. GCT employs one bus fleet.

Procurement: The next stop request requires support from the GCT fleet manufacturer to build a module for connecting a mobile app to their next stop functionality.

Traceability: The following system needs and requirements are supported by ET-6.

- **System Need:** The primary system need is:
    - **BT-SY-2.2** "The ATL RIDES Mobile App needs to be capable of providing hands-free, turn-by-turn directions based on user preferences and abilities to meet user needs." The need includes user needs that support hands-free actualization of on-board next stop request signal.
    - Additional needs include **TT-SY-3.1** and **TT-SY-3.2** (see Appendix C).
- **System Requirement(s):**
    - Requirements related to BT-SY-2.2 include 2.2.0-078.
    - Requirements related to TT-SY-3.1 and TT-SY-3.2 include 3.1.0-092, 3.1.0-093, 3.1.0-095, 3.1.0-096 and 3.2.0-105.

2.2.7. ET-7 Network Impedance API (Exchange #5)

Subsystems: ATL RIDES and STM data exchange

Description: The ATL RIDES app employs the Open Street Map (OSM) network in building paths for users. The OSM network incorporates pedestrian pathway links (with link distance, speed, and travel time attributes by mode), and a host of additional tags to represent pathway attributes. The STM carries historic and near-real-time (5-minute resolution) link operating conditions and is used with machine learning to predict shortest path routes under evolving congestion formation/dissipation conditions. The ST-CTN deployment will create a regional all-paths network, map this network to the STM network, and map this network to the OSM network. Phase 2 will yield a complete update to the OSM network structure to match the regional all paths network (and all node connections between roads and paths will be verified in this process).

As OSM evolves, pedestrian pathway links will contain the relevant tags needed to represent the impact of additional variables that affect pedestrian impedance for various Americans with Disabilities Act (ADA) mobility modes, such as the presence/absence of a pedestrian ramp or pavement disjoints that create barriers to wheelchair or stroller movement. Using impedance equations developed via crowdsourced research, OSM will eventually be able to use these link attribute tags to populate new impedance tags for each ADA mobility mode for each link. Hence, transportation planning and routing apps will be able to use these impedance values, rather than travel time alone, in shortest path routing between any origin-destination pair for specific ADA mobility modes.

For the ST-CTN deployment, the team will generate link impedance values for each ADA mobility mode in the STM for each pedestrian pathway link and generate link travel times for each ADA mobility mode to reflect SidewalkSim impedance functions. The Network Impedance API will transmit updated link travel time by ADA mobility mode to the ATL RIDES app server, so that these values can be employed in OTP routines. Network link impedance updates will be transmitted hourly, to reflect major changes in the conditions of pathway links (changes due to construction, elevator outages, etc.). Additional updates at the margin (within the last hour) will be supported and transmitted when requested by the app. Standard JavaScript Object Notation (JSON) communications between servers will support this feature.

Integration: The Network Impedance API does not currently exist. The following enhancements will be needed including new OSM attributes assigned to sidewalk features; development of additional impedance functions to accommodate 8 levels of user preferences and abilities. In Phase 2, the team will develop secure connections between servers using standard server-to-server protocols. The team will work with the OSM organization to promote additional attributes into the standard set of attributes as well as increased accuracy of network geometry and characteristics.

Procurement: Modifications by the STM developers to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability. This will entail generating an API that lists the impedances that are linked to the OSM network.

Traceability: The following system need and requirements are supported by ET-7.

- **System Need:** The primary system need is:

- **BT-SY-2.1.3** "STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., SidewalkSim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes."

- **System Requirement(s):**
  - The requirement related to BT-SY-2.1.3 includes 2.1.3-077.

2.2.8. ET-8 STM Composite/Architecture - Network Generation and Scalability

Subsystems: STM Platform

Description: The ST-CTN project will create an *all-roads, all-pathways network* for the Metro Atlanta region to support multimodal navigation through the transportation system (including navigation by ADA mobility modes). The team will update the STM network to match this comprehensive regional network and will reconcile this network with the OSM network (and all node connections between roads and paths will be verified in this process). Phase 2 will yield a complete update to the OSM network structure to match the regional *all paths* network. The network will first be demonstrated in the study area and then expanded to the region to demonstrate scalability.

Integration: The all-roads, all-pathways network does not currently exist for the Atlanta Metro area. In Phase 2, the team will develop the comprehensive all-roads, all-pathways by reconciling the ARC activity-based travel demand model (ABM), NAVSTREETS, and OSM networks (and link attributes) using the methods demonstrated for BikewaySim. The team will then generate an updated OSM network that represents the complete streets, complete paths network for the metro area and will coordinate with stakeholders to update existing OSM link structures for Metro Atlanta.

Procurement: A license to use NAVSTREETS data as a link-node data source is recommended. The BikewaySim network development effort demonstrated that NAVSTREETS data had more complete coverage and higher spatial accuracy than existing ABM and OSM network structures for roadways. If a license agreement cannot be executed at reasonable cost (or no cost) in Phase 2, the same reconciliation process can be accomplished with OSM and ABM alone (requires additional labor for spatial reconciliation).

Traceability: The following system needs and requirements are supported by ET-8.

- **System Needs:** The following system need relate to scalability and future growth and expansion of the system:
  - **BT-SY-2.1** The complete trip system functions (STM and ATL RIDES) need to be scalable to generate and accommodate multiple personalized trip plans and journeys for travelers simultaneously in order to be reliable and responsive to traveler requests and preferences.
  - **PT-SY-1.3** The system needs to generate a framework to transform values assigned to travel preferences into impedance values for the simulation models (e.g., SidewalkSim). (This need defines the core technology behind how trip plans are personalized for travelers)

- **FT-SY-8.1** The system needs to allow for future scalability or development in order to address user needs that are not within the scope of this project and will not be implemented in the initial roll out.
- **FT-SY-8.1.1** The system needs to be scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be needed to buy transit tickets or passes from public agencies.
- **FT-SY-8.1.2** The system needs to be scalable such that other geographic areas may be included in the future.
- **FT-SY-8.1.5** The system needs to be scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be mobility service access rights from private sector agencies such as bikeshare, ridehailing, microtransit services or others.

- **System Requirement(s):**
  - Requirements associated with BT-SY-2.1 include 2.1.0-046, 2.1.0-047.
  - Requirement associated with PT-SY-1.3 include 1.3.0-026 through 2.1.0-047 (these are also related to ET-10 Impact Assessment and Network Edge Cost Analysis).
  - The other needs include future ways the system needs to be scalable. Requirements to meet these needs will change over time.

2.2.9. ET-9 STM Simulator - Integrate New Features into SidewalkSim

Subsystems: STM Platform

Description: For the ST-CTN deployment, the team will generate link impedance values for each ADA mobility mode in the STM for each pedestrian pathway link and generate link travel times for each ADA mobility mode to reflect SidewalkSim impedance functions. For example, the absence of a curb ramp imposes a significant barrier to wheelchair travel. If a person in a wheelchair has to divert into the street and access sidewalk via driveway curb cuts rather than dedicated ramps, the relative disutility (impedance) of that route can be quantified as an increase in effective travel time on that route for those ADA mobility mode users. The initial literature review will identify and implement pedestrian pathway impedance factors in a manner similar to that in developing impedance factors for bicycle users (factors such as uphill grade, presence of trucks, left turn movements and other factors have been converted into time factors). For each impedance factor that is affected by facility design (e.g., pathway width sufficient to support a wheelchair) and condition (pavement disjoints that prevent wheelchair passage), the relevant data for each sidewalk link and element (ramp, curb cut, etc.) must be tracked as attributes within the network design. The team will update SidewalkSim and the STM to implement these new impedance factors and to track attributes by link and associated element.

Integration: The team will develop pedestrian pathway impedance functions (by ADA mobility mode) during Phase 2 of the project. Adding the computational elements to the STM raises no technical concerns associated with this subsystem. Carrying these features and attributes into the OSM network raises no technical concerns associated with this subsystem. Risks during software development will be managed using good configuration and coding practices.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-9.

- **System Need:** The primary system need that drives this technology is:
    - **NV-SY-6.1** The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator/ escalator outages) to ensure accuracy in the accessibility of routes.
- **System Requirement(s):**
    - The requirements that support ET-9 relate to all the datasets that are ingested to support the applications. In particular, the key requirements associated with this include:
    - 6.1.0-146 Data Governance
    - 6.1.0-147 Data Curation
    - 6.1.0-148 Data Quality Processes, and
    - Data ingestion requirements: 6.1.0-151, 6.1.0-152, 6.1.0-153, 6.1.0-154, 6.1.0-155, 6.1.0-156, 6.1.0-158, 6.1.0-160, 7.2.0-205, 7.3.0-208.

2.2.10. ET-10 STM Impact Assessment and Network Edge-Cost Analysis Engine Upgrade

Subsystems: STM Platform

Description: The STM predicts the lowest cost to traverse through the multi-modal transportation networks using predicted link impedance costs that are evolving in the network over space and time. The STM predicts the travel time across each link based upon the congested speeds that the model predicts will exist at the time the user arrives at each link, rather than the travel time that was observed for those links at the time user departed the trip origin. That is, the STM accounts for congestion formation and dissipation during the trip. The STM currently includes the ABM roadway network and the Metropolitan Atlanta Regional Transit Authority (MARTA) and State Road and Tollway Authority (SRTA) transit networks (based upon General Transit Feed Specification (GTFS) data). For the ST-CTN deployment, the team will integrate the all-roads, all pathways network, which significantly expands the network size by an order of magnitude, and computational costs are expected to increase significantly. During Phase 2, the team will upgrade database structures and modify processes used to improve the efficiency of network graph generation (screening non-optimal route segments from analyses via machine learning, and breaking pathway generation into smaller analytical tasks that can be distributed across processing cores).

Integration: The team will update and enhance the database engine and data structures for the ST-CTN deployment to improve the efficiency of network graph development and edge cost assessment during Phase 2 of the project.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system need and requirements are supported by ET-10.

- **System Need:** The primary system needs that drive this technology are:
  - **PT-SY-1.3** The system needs to generate a framework to transform values assigned to travel preferences into impedance values for the simulation models (e.g., SidewalkSim).
  - **NV-SY-6.1** The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator/ escalator outages) to ensure accuracy in the accessibility of routes.
- **System Requirement(s):**
  - Requirement associated with PT-SY-1.3 include 1.3.0-026 through 2.1.0-047 (these also related to ET- STM Composite/Architecture – Network Generation and Scalability).
  - Key real time data requirements associated with NV-SY-6.1 include 6.1.0-151 Ingest Traveler Feedback Data.

2.2.11. ET-11 STM Operational and Prediction Analysis Engine Trip Compliance Analysis

Subsystem: STM Platform

Description: For the ST-CTN deployment, the team will generate link impedance values for each ADA mobility mode in the STM for each pedestrian pathway link and generate link travel times for each ADA mobility mode to reflect SidewalkSim impedance functions. Although the literature review will identify impedance factors for pedestrian pathways, the team will continue to refine these factors over time. The best source of data to assess whether link impedance equations are valid is revealed preference data. The ATL RIDES app provides shortest path recommendations to users, and records the actual paths taken (origin-destination pairs and link traverse data). The team will compare paths taken to paths advised (trip compliance) and identify deviations that are likely related to systematic user response deviation and user response variability. The team will use the data in the ongoing calibration of impedance equations, the identification of additional significant pathway design and condition factors, and the identification of endogenous factors such as weather conditions for integration into the impedance equations by ADA mobility mode for the duration of Phase 3 implementation of the project. This subsystem is the research analytical engine used in the ongoing improvement of impedance equations by ADA mobility mode.

Integration: There is no current analytical engine for ongoing assessment of path deviation data and improvement of impedance functions. In Phase 2, the team will develop the data analysis and impedance equation improvement processes (research and development) and integrate them into the STM application.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-11.

- **System Needs:** The major system needs that drive this technology are:
  - **BT-SY-2.1.3** STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., SidewalkSim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes.
  - **PT-SY-1.3** The system needs to generate a framework to transform values assigned to travel preferences into impedance values for the simulation models (e.g., SidewalkSim).
- **System Requirement(s):**
  - Requirements associated with BT-SY-2.1.3 include 2.1.3-077 Continuous Publication of Network Impedance API.
  - Requirement associated with PT-SY-1.3 include 1.3.0-026 through 2.1.0-047 (these also related to ET- STM Composite/Architecture – Network Generation and Scalability).

2.2.12. ET-12 STM-ATL RIDES Trip and Infrastructure Feedback (Exchange #4)

Subsystems: STM Platform and ATL RIDES (Exchange #4)

Description: The ATL RIDES app provides shortest path recommendations to users, and records the actual paths taken (origin-destination pairs and link traverse data). The team will use these data in the ongoing development and calibration of impedance equations. This exchange feature transmits data from ATL RIDES to the GA Tech secure data server for use in research activities. There are two major datasets that traverse this flow:

- ATL RIDES log files with traveler preference, trip plans and trace data
- Traveler feedback that includes trip surveys, travel experience and changes to the infrastructure.

The interface with the log files will be implemented as a scheduled upload from the ATL RIDES data broker to the STM data broker. The technology is common although integration of the datasets will be a new modification to the STM.

The delivery of the feedback data, specifically for infrastructure changes is currently implemented in the ATL RIDES “Rate my Ride” function including documenting user feedback in an existing app. The STM also deployed a similar app for Commute Atlanta where the data processing procedures are in place and may be leveraged for this project. Both these functions will contribute to modify the code in the STM and ATL RIDES subsystems.

Integration: There are no current connections between ATL RIDES servers and GA Tech servers for the STM Platform. In Phase 2, the team will develop secure connections between servers using standard server-to-server open interfaces (between the STM Platform and other subsystem servers). The teams will also coordinate the reuse of code that has been developed for other projects.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-12.

- **System Needs:** The major system needs that drive this technology are:
  - **RP-SY-7.2** The system needs to collect user input (using crowdsourcing methods) about disruptions and obstructions to their travel during or after their travel.
  - **RP-SY-7.3** The system needs to provide anonymized information about trip performance to the performance monitoring module (in the STM subsystem) that details traveler behavior to help improve trip plan customization for users.
- **System Requirement(s):**
  - Requirements associated with Needs RP-SY-7.2 include 7.2.0-205
  - Requirements associated with Needs RP-SY-7.3 include 7.3.0-208, 7.3.0-211, 7.3.0-212, 7.3.0-213, 7.3.0-214, 7.3.0-215, 7.3.0-216, 7.3.0-217, 7.3.0-218.

2.2.13. ET-13 STM Dynamic Data Broker to Ingest New Data Sources

Subsystems: STM Platform

Description: The STM carries historic and near-real-time link operating conditions from any available data source that is capable of delivering data at the specified spatial and temporal resolution; link-based at 5-minute resolution. The STM data are used with machine learning to predict shortest path/lowest impedance value routes through the multi-modal transportation networks using predicted link impedance values that are evolving in the network over space and time. For the ST-CTN deployment, the team will integrate the all-roads, all pathways network and will coordinate with data providers to deliver spatial and temporal data into the system for use in machine learning. The system is provider agnostic and is designed to incorporate as many data feeds as desired. The machine learning processes automatically account for the relative benefit of data from each provider in predictive equations (machine learning models do not reflect causality; they simply represent the relationships that provide the best predictions based upon available data).

Datasets, feeds, and streams anticipated to be ingested by the dynamic data broker include:

- Exchange #6: ATIS, BSM, MAP, SPaT (currently implemented but anticipated to be updated during the project), ATMS (NaviGator, MaxTime/View), and other GDOT and GC DOT data.

- Exchange #4: STM ingesting ATL RIDES data from traveler feedback and crowdsourced data.

- External Data sources: NOAA, commercial traffic data, static network data sources.

A full list of the datasets is included in the [DMP].

Integration: In Phase 2, the team will develop the data broker to ingest datasets that support generating and updating the impedance values associated with the whole network model. The data includes link speeds, traffic volumes, and any other available attributes, into the STM from all providers selected for integration. Some datasets will apply publish/subscribe or request/response orchestration to acquire the datasets, other methods include data pulls (from the STM). The frequency, timing, content size and scale will be developed during the system design.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystem and external system integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-13.

- **System Needs:** Many of the data that drive this technology are new. To that end, the following systems needs are the major drivers of the ET:
  - **BT-SY-2.1.3** "STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., SidewalkSim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes." requires that the STM can ingest static and real time data from the CV ITS Hub server including SPaT, MAP, BSM, ATIS and other CV and Advanced Traffic Management System (ATMS) streaming and event-based datasets.
  - **NV-SY-6.1** The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator/ escalator outages) to ensure accuracy in the accessibility of routes.
  - **FT-SY-8.1.1** The system needs to be scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be needed to buy transit tickets or passes from public agencies.
- **System Requirement(s):**
  - Requirements associated with Need BT-SY-2.1.3 include 2.1.3-077.
  - Requirements associated with Need NV-SY-6.1 include 6.1.0-147, 6.1.0-148, 6.1.0-149, 6.1.0-150, 6.1.0-151, 6.1.0-152, 6.1.0-153, 6.1.0-154, 6.1.0-155, 6.1.0-156, 6.1.0-158, 6.1.0-160, 6.1.0-171, 6.1.0-172, 6.1.0-173, 6.1.0-178.
  - Requirements associated with Need FT-SY-8.1.1 include 8.1.1-220.

2.2.14. ET-14 STM Performance Monitoring Dashboard PMESP Implementation

Subsystem: STM Platform (Performance Monitoring Dashboard)

Description: The performance monitoring dashboard ingests the data from the different subsystems and generates metrics for tracking performance of the different subsystems as well as the overall system. The performance monitoring system will generate the metrics in near-real-time or at regular intervals depending on the performance measure update frequency requirements, the input data update frequency, and the quality of the data. For example, a performance metric that depends on a sparse data-stream or a noisy data stream (with random anomalies) might have to be reported on a less frequent basis to ensure that there is sufficient data in the calculation interval to ensure a robust computation.

Current Deployment: Several of the private-vehicle based performance measures are already calculated in the system deployed in the course of the Advanced Research Projects Agency-Energy (ARPA-E) project and the North Avenue Smart Corridor project. The team has developed algorithms and systems that account for sparseness, noise, and high velocity of the data for several of the data feeds. However, a large majority of the performance measures are specific to this project. While the intermediate data handling modules are in place, the final computations to generate the metrics are not available for all of the measures in the current deployment.

Integration: In Phase 2, the team will develop the equations and algorithms for accurate, efficient, and robust calculation of the performance metrics. The team will also develop the various research server computational systems to pull STM data, research server data, and PII data to prepare summary tables and plots for each performance measure.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-14.

- **System Need:** The primary system need that drives this technology is:
  - **RP-SY-7.3** The system needs to provide anonymized information about trip performance to the performance monitoring module (in the STM subsystem) that details traveler behavior to help improve trip plan customization for users.
- **System Requirement(s):**
  - Requirements associated with RP-SY-7.3 include 7.3.0-219 (Analyze trip performance).
  - Presentation of the information is subject to Requirement 2.3.0-083 WCAG 2.1 or Higher.

2.2.15. ET-15 ATL RIDES Turn-By-Turn Direction Support and Indoor Navigation

Subsystems: ATL RIDES

Description: ATL RIDES will provide users with turn-by-turn direction support if desired. The app will rely on the user's mobile device's location services, global positioning system (GPS) and Wi-Fi-based, functionality, to locate the user along their trip itinerary and provide turn by turn directions on-screen in a manor compatible with accessibility apps such as screen readers. Within stations, underground tunnels, and other cases when the app user's mobile device loses GPS connection, the mobile device's location services module may fall back to deriving location information from the Wi-Fi and other networks it connects to, but additional supplemental location devices, such as Bluetooth Low Energy (BLE) or quick response (QR) codes, may be necessary to support indoor turn-by-turn navigation for users.

ATL RIDES currently provides turn-by-turn instructions as part of each trip itinerary. The ATL RIDES mobile app relies on the mobile device location services for the user’s current location. The app does not currently provide a heads up of the next turn-by-turn direction based on the user’s location. The ATL RIDES routing engine relies on the GTFS-pathways data standard for indoor wayfinding, accessibility, and directions information, but does not currently have functionality to supplement location and orientation data from other navigation sensors.

Integration: The existing ATL RIDES routing engine and mobile apps functions include the core building blocks to implement this feature. The following new features will be developed to support this:

- Display user’s next turn-by-turn direction based on current location.
- Means of consuming supplemental location information from beacons to support indoor navigation such as BLE.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability. Procurement of supplemental location beacons as described above for indoor navigation.

Traceability: The following system needs and requirements are supported by ET-15.

- **System Needs:** The major system needs that drives this technology are:
  - **BT-SY-2.2** The ATL RIDES Mobile App needs to be capable of providing hands-free, turn-by-turn directions based on user preferences and abilities to meet user needs.
  - **BT-SY-2.3** The system needs to be compatible with open standards that are embedded or used in devices including mobile phones and connected assistive devices.
  - **BT-SY-2.6** The system needs to activate automated messages and alerts, as well as re-routing based on real-time information consistent with the traveler's preferences while the traveler is executing their travel.
  - **NV-SY-6.2** The system needs to interface with facility or third-party communications assets using protocols available on smartphones (e.g., near-field communication (NFC), Bluetooth, Wi-Fi) and also use standardized navigation or wayfinding messages to communicate with travelers.
- **System Requirement(s):**
  - Requirements associated with BT-SY-2.2 include 2.2.0-078.
  - Requirements associated with BT-SY-2.3 include 2.3.0-080 and 2.3.0-082.
  - Requirements associated with BT-SY-2.6 include 2.6.0-090 and 2.6.0-091.
  - Requirements associated with NV-SY-26.2 include 6.2.0-181 to 6.2.0-198.

2.2.16. ET-16 ATL RIDES Notifications and Event Triggers

Subsystem: ATL RIDES

Description: The ATL RIDES app will provide users with notifications and event triggers throughout their journey based on their preferences (e.g., voice, push notification text, and/or haptic feedback).

Integration: The existing ATL RIDES routing engine and mobile apps functions include the core building blocks to implement this feature. The following new features will be developed to support this:

- Integration with native mobile software development kit (SDK) components for voice and haptic feedback
- Expansion of user account preferences to include spectrum of notification and event trigger communication (user interface) options

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-16.

- **System Needs:** The major system needs that drive this technology are:
  - **PT-SY-1.4** The system needs to allow travelers to customize the UI of the application based on their abilities or preferences.
  - **BT-SY-2.4** The system needs to be designed such that travelers will be able to customize how notifications are received based on their abilities or preferences.
- **System Requirement(s):**
  - Requirements associated with PT-SY-1.4 include 1.4.0-039 through 1.4.0-041.
  - Requirements associated with BT-SY-2.4 include 2.4.0-084 and 2.4.0-085.

2.2.17. ET-17 ATL RIDES Trigger Settings

Subsystem: ATL RIDES

Description: The ATL RIDES app will include user settings to allow the user’s mobile device to connect to infrastructure and transit assets (pedestrian crossing request, bus stop request), as well as sending notifications to a specified asset when approaching / arriving at a transition point including intersection crossings, bus stops, and building entrances.

Integration: The existing ATL RIDES routing engine and mobile apps functions include the core building blocks to implement this feature and can leverage native mobile SDK components to handle communication with infrastructure and transit assets. The following new features will be developed to support this:

- Expansion of user account settings to include ability to connect to infrastructure and transit assets as needed
- Integration of communication components to send notifications to infrastructure/transit assets as needed. These will be consistent with ET-1, ET-3, ET-4, and ET-5.

Procurement: Modifications to existing software will be applied to meet the requirements of associated subsystems integration, interface functionality, and system performance and scalability.

Traceability: The following system needs and requirements are supported by ET-17.

- **System Needs:** The major system needs that drive this technology are:
    - **TT-SY-3.1** The system needs to provide a method for a traveler to send a stop request to an approaching transit vehicle. The stop request may also identify special needs of the traveler. (Also includes TT-SY-3.2)
    - **IC-SY-4.1** The system needs to connect to traffic signal system infrastructure to enable travelers to activate crosswalk signals using a hands-free method, or automatically using their trip plan and location so that the traveler is able to complete their trip based on their preferences and abilities. (Also include IC-SY-4.2)
- **System Requirement(s):**
    - Requirements associated with TT-SY-3.1 and 3.2 include 3.1.0-92 through 3.1.0-92, and 3.2.0-105 and 3.2.0-106 (Connection Protection application).
    - Requirements associated with IC-SY-4.1 and 4.3 include 4.1.0-112 through 4.1.0-127 and 4.3.0-136 (PED-SIG application).

3. Technology Readiness Level (TRL) Assessment

This section will provide the TRL for each ET item listed in Section 2 of this document. Applying the TRL is a formal process that supports the assessment of technologies and provides the ability to compare the levels of maturities among different technologies. During the assessment, technical gaps and questions that point toward next steps in the technology's development can be uncovered, followed by ST-CTN Executive Management Team (EMT) and system developers strategizing resources and procurement approaches needed to develop and implement the system solution. Many of the gaps will lead to discussions anticipated in Phase 2 to develop the technical solutions to achieve the goals, objectives, and requirements of the project. Using the method for generating the inventory described in **Section 2.1**, each ET is assigned a TRL and related justification in this section.

3.1. TRL Assessment Process

This section describes the process used to identify and justify the TRL for each ET. The technology assessment review gathered information on the technologies from a number of sources. They include:

- Current experience supported by operations in more than one deployment. For example, open-source software which is deployed in more than a dozen implementations can be considered current experience.
- Commercial viability in which more than one vendor offers a similar technology or solution.
- Interviews with experts who have or are currently piloting the technology that addresses similar application concepts and requirements.
- Literature scan and review that describe demonstration or pilot projects that address similar application concepts and requirements.

The TRLG includes questions that provide a method for ranking and justifying the TRL. Using data gathered from multiple sources, the project team reviewed and responded to the questions posed in the TRLG and listed in **Table 5**.

Table 5. TRL Assessment Requirements (source: [TRLG])

TRL Rank	TRL Name	Requirements
1	Basic principles and research	• Do basic scientific principles support the concept? • Has the technology development methodology or approach been developed?
2	Application formulated	• Are potential system applications identified? • Are system components and the user interface at least partly described? • Do preliminary analyses or experiments confirm that the application might meet the user need?
3	Proof of concept	• Are system performance metrics established? • Is system feasibility fully established? • Do experiments or modeling and simulation validate performance predictions of system capability? • Does the technology address a need or introduce an innovation in the field of transportation?
4	Components validated in laboratory	• Are end-user requirements documented? • Does a plausible draft integration plan exist, and is component compatibility demonstrated? • Were individual components successfully tested in a laboratory environment (a fully controlled test environment where a limited number of critical functions are tested)?
5	Integrated components demonstrated in laboratory environment	• Are external and internal system interfaces documented? • Are target and minimum operational requirements developed? • Is component integration demonstrated in a laboratory environment (i.e., fully controlled setting)?
6	Prototype demonstrated in relevant environment	• Is the operational environment (i.e., user community, physical environment, and input data characteristics, as appropriate) fully known? • Was the prototype tested in a realistic and relevant environment outside the laboratory? • Does the prototype satisfy all operational requirements when confronted with realistic problems?

TRL Rank	TRL Name	Requirements
7	Prototype demonstrated in operational environment	• Are available components representative of production components? • Is the fully integrated prototype demonstrated in an operational environment (i.e., real-world conditions, including the user community)? • Are all interfaces tested individually under stressed and anomalous conditions?
8	Technology proven in operational environment	• Are all system components form-, fit-, and function-compatible with each other and with the operational environment? • Is the technology proven in an operational environment (i.e., meets target performance measures)? • Was a rigorous test and evaluation process completed successfully? • Does the technology meet its stated purpose and functionality as designed?
9	Technology refined and adopted	• Is the technology deployed in its intended operational environment? • Is information about the technology disseminated to the user community? • Is the technology adopted by the user community?

The review identified several gaps that require more design and solutioning and may require mitigation strategies to ultimately achieve project goals and objectives. The mitigation plan is included in **Section 4.2**. The technologies inventoried in this current version of the ETRA will not preclude a feature from being implemented if an alternative technology becomes available that can be integrated into the solution to achieve a user need.

3.2. TRL Ratings for Inventoried Enabling Technologies

This section identifies every ET item inventoried in **Section 2.2**. Each ET item **that scores at or below 7** has a subsection with a header that contains the ET Unique identifier, ET Name, and Assessed TRL level (1 through 7). The paragraph following the header includes a concise summary of the reason(s) for ranking the TRL. The summary may include literature reviewed, interviews, existing deployments by project stakeholders or third parties to justify the level. Methods and conditions needed to address gaps and solutioning will be briefly described for each of these ET items that score at or below 7. A summary of the ET and their TRL with a link to the justification is listed in **Table 6. Table 6** also includes a brief justification for ET-1 which scored 9, excluding it from the more detailed later subsections. ET-2 and ET-4 were removed from the project. ET-2 was combined with ET-13 and ET-4 is being implemented by the GDOT/GC Smart Corridor project.

Table 6. Summary TRL for each ET Item

ET-#	TRL	Justification Description (section #)
ET-1	9	The SMUG will integrate commercial off-the-shelf (COTS) solutions that has been used in this capability in prior deployments in the region. These routers can be procured as commercial off-the-shelf hardware or software with firewall functionality.
ET-2	8	Removed – merged with ET-6.
ET-3	6	Section 3.2.1
ET-4	6	Removed -- application will be implemented by the Smart Corridor project (out of scope of the ST-CTN). The limited expanded functionality to support the ST-CTN system is merged with ET-5.
ET-5	6	Section 3.2.2
ET-6	3	Section 3.2.3
ET-7	6	Section 3.2.4
ET-8	6	Section 3.2.5
ET-9	5	Section 3.2.6
ET-10	5	Section 3.2.7
ET-11	3	Section 3.2.8
ET-12	6	Section 3.2.9
ET-13	7	Section 3.2.10
ET-14	6	Section 3.2.11
ET-15	6	Section 3.2.12
ET-16	6	Section 3.2.13
ET-17	6	Section 3.2.14

3.2.1. ET-3 Mobile Accessible Pedestrian Application (PED-SIG) TRL 6

Justification Summary: Based on experience supported by operational deployments in current CV deployments particularly in Tampa and New York City, the PED-SIG implementation will apply current center-to-center messaging protocols and security equipment to communicate between the ATL RIDES and CV subsystem (Traffic Management tools) to request walk signal actuation. The North Avenue PED-SIG deployment, when it is completed, will provide a template for implementing similar request messages that will be leveraged as part of the ST-CTN project.

Table 7. ET-3 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment is fully known • System has been implemented using similar message sets and protocols • Requires development of final data specifications, security, and programming.

3.2.2. ET-5 Transit Connection Protection (aka Transit Stop Request (TSR)) – TRL 6

Justification Summary: Because the connection protection application is similar to a transfer connection protection use case deployed by the GCT CAD vendor for several transit agencies, this technology will be modified to allow a third party (ATL RIDES) to request a connection rather than a transit operator. The modification will require a third-party API transaction set that can be used by ATL RIDES to request service. The API will be jointly developed by the GCT CAD and the ATL RIDES developers. ATL RIDES contains functions that track and trigger events based the proximity of travelers to transition points along their preloaded trip plans.

Table 8. ET-5 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Software modifications will be necessary. • The environment has been tested and operated for the operator functions, the modifications will need to be developed and tested for a third-party request and confirmation. • Security protocols will need to be put in place. Since this is a center to center network, a virtual private network or similar network link will be implemented to ensure trusted communications. • Request message timing and latency will need to be evaluated and refined during the testing.

3.2.3. ET-6 Transit Next Stop Request – TRL 3

Justification Summary: Each bus vendor integrates their next stop request control, signs and indicators using different protocols and methods. The effort will require working with the GCT bus manufacturer to access the next stop request controls and then build a module into the onboard control software (from the CAD/automatic vehicle location (AVL) vendor) to activate the appropriate circuitry. Robust testing will be needed to ensure that the functionality does not disrupt or conflict with the current functionality. Each fleet type (bus make and model) requires a custom application and so the deployment cannot be scaled to other transit fleets.

Table 9. ET-6 TRL

TRL	TRL Name	Justification
3	Proof of concept	• Work has been done to integrate third party applications with vehicle control systems, however, it is not clear if this has been done with the GCT bus fleet. • Custom software will be needed and robust testing to ensure the system doesn’t conflict with current operations.

3.2.4. ET-7 Network Impedance API (Exchange #5) – TRL 6

Justification Summary: The STM currently contains the regional major arterial roadway network and calculates impedance for roadway and transit links based upon five-minute link speeds, vehicle operating cost, fares, and tolls (all converted to link travel time). The sidewalk network follows the same specification. Adding the sidewalk network to the STM raises no technical concerns associated with this subsystem.

In addition, the SidewalkSim (the analog of RoadwaySim for pedestrian pathways) is operational in a stand-alone server format and currently calculates pedestrian pathway link impedance using preliminary functions developed for testing. Hence, the computational system is in place to generate pedestrian pathway impedance factors using any functional specification including transforming the impedance link-node identifiers to a reference OSM network used by both the ATL RIDES and STM subsystems. The team will develop project impedance functions (by ADA mobility mode) during Phase 2 of the project. Adding the computational elements to the STM raises no technical concerns associated with this subsystem.

Table 10. ET-7 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment is fully known. • Similar API demonstrated in ARPA-E project for different data streams. • Requires development of final data specifications, security, and programming. Since this is a center to center network, a virtual private network or similar network link will be implemented to ensure trusted communications.

3.2.5. ET-8 STM Composite/Architecture - Network Generation and Scalability – TRL 6

Justification Summary: The STM development team uses the ABM network in planning, energy, and emissions analyses (and to develop sub-regional Vissim traffic simulation models). The 2021 regional ABM employs a 150,000-link transportation network composed of all major arterials and higher functional classification roadways. The team has also already mapped all ABM links in the 150,000-link network to a prior ARC-200,000-link network (used in the Department of Energy (DOE) ARPA-E project and in the current STM network) and older 75,000-link ABM networks.

The SidewalkSim link-and-node networks (independent of roadway networks) have already been developed for the City of Atlanta, City of Sandy Springs, City of East Point, Clayton County and various sub-regions in the metro area. These networks are compatible with STM network specifications, but sidewalk networks are not currently integrated into the STM. Integrating sidewalks into the STM raises no technical concerns.

Additionally, the BikewaySim link-and node networks include all roads, bicycle paths, and shared-use facilities that can be traversed by bicycles. Hence, BikewaySim networks include local roads that are not included in the ABM networks. The team recently constructed a BikewaySim *all roads, all-paths network* for a 12-square-mile BeltLine Bicycle Activity Study Area (Midtown, Piedmont Park, Morningside, Virginia-Highlands, Old Fourth Ward, Ansley Mall, Atlantic Station, and the GA Tech campus). This network is coded for integration into the STM. The system is operational in a stand-alone server format and currently calculates bicycle pathway link impedance using preliminary functions developed for testing (includes impedance for uphill grade, presence of truck traffic, left turn movements, etc.). Given that the procedures have been tested, the team does not anticipate that generating an all-roads, all-pathway networks will create any technical concerns.

Table 11. ET-8 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment, data standards, and network development procedures are fully known. • Whole roads and paths network developed for BikewaySim study area in 2021 (reconciles ABM, NAVSTREETS, and OSM networks). • Requires labor for quality assurance/quality control (QA/QC), a data license agreement (or additional QA/QC labor in absence of a data license), and programming.

3.2.6. ET-9 STM Simulator - Integrate New Features into SidewalkSim – TRL 5

Justification Summary: The current SidewalkSim link-and-node network (independent of roadway networks) has already been developed for the City of Atlanta, City of Sandy Springs, City of East Point, Clayton County and various sub-regions in the metro area. These networks are compatible with STM network specifications, but sidewalk networks are not currently integrated into the STM. Integrating sidewalks into the STM raises no technical concerns because the network is formulated as a graph.

Additionally, SidewalkSim (the analog of RoadwaySim for pedestrian pathways) is operational in a stand-alone server format and currently calculates pedestrian pathway link impedance using preliminary functions developed for testing (with time impedance values for various ADA design criteria and condition defects per 50' sidewalk section, per ramp, and per curb cut). Hence, the computational system is in place to generate pedestrian pathway impedance factors using any functional specification.

Table 12. ET-9 TRL

TRL	TRL Name	Justification
5	Integrated components demonstrated in laboratory environment	• External and internal system interfaces are documented. • Operational requirements have been developed. • Component integration (calculation of impedance per route) has been demonstrated using placeholders from the literature in a laboratory environment. • Prototype demonstrated in an environment for BikewaySim, a modal network similar to SidewalkSim. • Requires development of ADA mobility mode impedance functions from literature and translation into Python code.

3.2.7. ET-10 STM Impact Assessment and Network Edge-Cost Analysis Engine Upgrade – TRL 5

Justification Summary: The current STM shortest path processing in the DOE ARPA-E TRANSNET project were significantly enhanced by breaking network graph creation into sub-zones. Expanding this improvement to network graph generation for each individual ADA mobility mode should provide further efficiency improvements. Multiple database structures were tested during the TRANSNET project. A similar process will be necessary for the ST-CTN project.

Table 13. ET-10 TRL

TRL	TRL Name	Justification
5	Integrated components demonstrated in laboratory environment	• External and internal system interfaces were documented for the ARPA-E project. • Target and operational requirements were developed. • Component integration was demonstrated in a laboratory environment (i.e., fully controlled setting). • Requires upgrades to database engines and efficiency enhancements are required for motor vehicle modes that experience congestion to improve system speed.

3.2.8. ET-11 STM Operational and Prediction Analysis Engine Trip Compliance Analysis – TRL 3

Justification Summary: The STM team has developed impedance functions based upon relationships and models reported in the literature. Additional impedance functions that correspond to user preference and abilities, refined by user feedback will be developed during Phase 2 of the project.

Table 14. ET-11 TRL

TRL	TRL Name	Justification
3	Proof of concept	• System performance metrics and end user requirements are established. • Feasibility of using revealed preference travel data to improve impedance functions (route taken vs. route provided) is fully established in the literature. • Requires development of machine learning processes to identify improved variables and coding to implement updated functions (ongoing).

3.2.9. ET-12 STM-ATL RIDES Trip and Infrastructure Feedback (Exchange #4) – TRL 6

Justification Summary: The STM servers currently manage trip-based and traverse-based data from instrumented vehicles (with second-by-second position resolution) as demonstrated in **Commute Atlanta** and other projects. The STM is also structured to receive and process vehicle-based and app-based user data. These functions will be augmented to accommodate feedback using the existing Sidewalk Scout app code (see ConOps for more detailed discussion on Sidewalk Scout) which will be integrated into the ATL RIDES app features.

Table 15. ET-12 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• ATL RIDES already has the capability to send user inputs to the server and to integrate third party software to collect data from user. • STM has prior capability of integrating monitored activity data into the system. • Requires specification of data flows and formats, data security protocols, and programming. Since this is a center to center network, a virtual private network or similar network link will be implemented to ensure trusted communications.

3.2.10. ET-13 STM Dynamic Data Broker to Ingest New Data Sources – TRL 7

Justification Summary: In the DOE ARPA-E TRANSNET project, the STM team developed applicable data broker functions to ingest all GDOT NaviGAtor data (over a period of 20 years), SRTA toll system data (two years on I-85), and private and modelled link and speed data for the entire metro Atlanta area. The broker services will be extended to include new data sources including CV data (from Exchange # 6 from **Figure 3** and **Table 2**).

Table 16. ET-13 TRL

TRL	TRL Name	Justification
7	Prototype demonstrated in operational environment	• System includes modules to ingest NaviGAtor ITS link-based data, SRTA tolling data, AirSage link and corridor performance data, ABM-model outputs, Vissim outputs, and monitored second-by-second data. • Each data source requires a new module and updates as data flows from providers change. • Interfaces are all operational under ongoing conditions. • No stress testing has been conducted for AVL data (max connections was 500 vehicles) nor for regional expansion.

3.2.11. ET-14 STM Performance Monitoring Dashboard PMSE Plan Implementation – TRL 6

Justification Summary: The Performance Monitoring Dashboard will be driven by the PMESP requirements. The technologies for storing, analyzing and presenting the data are mature. However, some of the analytics will require innovations in developing algorithms for generating the measures. Currently, several of the private-vehicle based performance measures are already calculated in the system deployed in the ARPA-E project and the North Avenue Smart Corridor project. The team has developed algorithms and systems that account for frequency, noisiness, variability in data quality and signal downtime for several of the data feeds. However, a majority of the performance measures are specific to this project; therefore, some new interface elements will need to be designed and coded for this project. While the intermediate data handling modules are in place, the final computations to generate the metrics are not available for all of the measures in the current deployment.

Table 17. ET-14 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• ATL RIDES already has the capability to send user inputs to the server. • STM has prior capability of integrating monitored activity data into the system. • The technologies for storing, analyzing, and presenting the data are mature. • Performance Monitoring Dashboard has prior capability of generating several of the measures in near-real-time. • Requires specification of data flows and formats, data security protocols, and programming/computation methods. Since this is a center to center network, a virtual private network or similar network link will be implemented to ensure trusted communications.

3.2.12. ET-15 ATL RIDES Turn-By-Turn Direction Support and Indoor Navigation TRL 6

Justification Summary: Turn-by-turn directions based on the user's current location builds upon the robust building blocks of existing functionality within ATL RIDES platform. The new components to this technology, primarily relying on beacons, such as BLE, for supplemental location information in the indoor navigation context have been deployed and proven in similar operational environments, such as for BLE 'check in check out' location-based fare payment systems [CICO], pedestrian crossing applications [PEDPAL], and wayfinding technology for people with vision loss [BLE].

Table 18. ET-15 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment is known. • ATL RIDES currently provides turn-by-turn directions for users in the trip itinerary. • Systems for providing supplemental location information have been demonstrated in comparable environments. • Requires selection/deployment of supplemental location information and integration into ATL RIDES app.

3.2.13. ET-16 ATL RIDES Notifications and Event Triggers – TRL 6

Justification Summary: The ATL RIDES app already has the ability for users to set preferences regarding notification/event trigger method. Currently, users can receive notifications via email, SMS and mobile device push notification. The enhancement to enable notification via text-to-speech voice messages and haptic feedback will require the implementation of tested, proven components within native mobile SDKs. These features have already been implemented in many mobile app tools [APP].

Table 19. ET-16 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment is fully known and deployed. • ATL RIDES currently includes mechanism for sending notifications and event triggers to users. • Voice and haptic feedback notification are available within native mobile app SDKs and are widely implemented by production use mobile apps.

3.2.14. ET-17 ATL RIDES Trigger Settings – TRL 6

Justification Summary: The ATL RIDES app already has the ability for users to define their notification settings as a saved account preference. This feature will be expanded to include settings for connection/communication to infrastructure/transit assets. Native mobile communication components will be leveraged to handle connection to infrastructure/transit assets. These components are widely used by other apps for communication to other devices/technology and have been applied/proven in the transportation context.

Table 20. ET-17 TRL

TRL	TRL Name	Justification
6	Prototype demonstrated in relevant environment	• Operational environment is fully known. • ATL RIDES currently includes structure/framework for stored user preferences about notifications/communication. • Native mobile app SDKs include components for connection to and communication with other devices/assets. These have been implemented and tested within the transit/transportation context for similar purposes to what is planned for this feature.*

*Developer guides are available from Apple (for iOS) and Google (for Android) developers. These include: https://developer.apple.com/documentation/uikit/accessibility_for_uikit and https://developer.android.com/guide/topics/ui/accessibility/apps.html.

4. Risk Assessment

This section describes and discusses all known and anticipated risks that may affect the deployment related to the technology readiness of system components. For each ET, the known and potential risks are described in **Table 21** and related mitigation plans are described in **Table 22**. These identified ET risks will be integrated into the ST-CTN Risk Registry and monitored until the risk has been eliminated or throughout the life of the project.

4.1. Assessing Risk

Table 21 describes the risks associated with the ETs identified for the ST-CTN project. Each risk is uniquely identified (Risk ID) and described in the Risk Description column. The associated ETs are identified in the column labeled ET ID and the level of impact to the project is assessed as low, medium, or high. The qualitative assessments have been associated with a quantitative score to be consistent with the ST-CTN project risk registry, i.e., an impact level of high is equivalent to a score of 5. The risks described below are included in the ST-CTN project risk registry and are regularly monitored.

The criteria to assign an impact level is as follows:

- **Low (1):** a technology impact is limited or restricted to a single component, function or information element of the system that can be avoided through designing an alternative solution or using an alternative technology.
- **Medium (3):** a technology impact affects one or more components, functions or information elements of the system that can use alternative solutions and/or technologies that are applied during design or early deployment.
- **High (5):** a technology impact affects system operations or user safety and may require additional equipment or support services to avoid the impact.

Table 21. Risk Assessment for Each ET

Risk ID	ET ID	Risk Description	Impact Level
R-1	ET-1, ET-3, ET-5, ET-6, ET-7, ET-8, ET-9, ET-10, ET-11, ET-12, ET-13, ET-14, ET-15, ET-16, ET-17	**Resources** – Time, money, and staffing availability have the potential to impact the effectiveness of ETs. As with any project, reasonable expectations need to be defined for the anticipated schedule, budget, and staff hours required to achieve the goals and objects of the project.	High

Risk ID	ET ID	Risk Description	Impact Level
R-2	ET-5, ET-6, ET-12, ET-16, ET-17	**Subsystem Deployment Interdependencies** – The ST-CTN system is dependent on the integration and enhancement of existing systems. Several of these systems are currently being deployed or upgraded outside of the scope of the ST-CTN project. Specifically, the CV and ATL RIDES subsystems are currently being deployed by GDOT/GCDOT and ATL respectively. In addition, GCT is upgrading their CAD and AVL systems which will be leveraged to support CV applications in the ST-CTN system. It will be critical that these efforts remain on-schedule such that integration and enhancements necessary for the ST-CTN system can be implemented.	High
R-3	ET-1	**Procurement Challenges** – The SMUG may be determined to be a software or hardware solution. If this technology is determined to be a hardware solution, a potential risk in the form of procurement delay has been identified due to existing delays in the industry because of computer chip shortages.	Low
R-4	ET-1, ET-3	**Integration Challenges (Existing Technologies)** – Integration challenges can be somewhat unpredictable and difficult to resolve. There is anticipated risk associated with integrating existing technologies leveraged for the ST-CTN project, including: the SMUG, CV and traffic data feeds, and PED-SIG.	High
R-5	ET-5, ET-6, ET-7, ET-12	**Integration Challenges (New Technologies)** – There is anticipated risk associated with integrating new technologies leveraged for the ST-CTN project, including: PTI, TSR, transit next stop request, network impedance API, and the STM-ATL RIDES trip and infrastructure feedback.	High
R-6	ET-1, ET-3, ET-5, ET-12, ET-17	**Varied Institutional Security and Privacy Requirements** – Across the three subsystems, there are several differing security and privacy policies that drive system requirements. These will need to be reconciled and implemented across the system and within the institutional constraints.	High

Risk ID	ET ID	Risk Description	Impact Level
R-7	ET-3, ET-16, ET-17	**Subsystem Communication** – Current communication methods for the CV subsystem rely on 5.9 GHz, C-V2X methods. With the reallocation of a portion of the spectrum, there is a potential risk of spectrum interference that could cause communication challenges in the CV subsystem. However, given the ST-CTN project is only relying on data generated by the CV subsystem, the loss of spectrum will only degrade analyzing performance of the system, and will not impact users of the system.	Medium
R-8	ET-7, ET-8, ET-10, ET-11, ET-16, ET-17	**System Latency** – Several of the applications include strict operational timing constraints. Knowing the communications latency from the trigger event, generation of the message, receipt, acknowledge and actuation is critical to implementing the system. Since there are several subsystems interacting, the risk includes: synchronizing time and calculating the time difference for each leg.	Low
R-9	ET-7, ET-8, ET-11, ET-12, ET-14, ET-15, ET-16, ET-17	**Data Quality and Integrity** – As a data driven system, the quality and consistency of data throughout the system will impact whether services can be offered and if the information is accurate. Furthermore, because this is a system of systems, being able to track trips through transactions with third parties or subsystems will be critical to analyze the effectiveness and performance of the system.	Medium
R-10	ET-9, ET-10, ET-11, ET-12, ET-13, ET-14	**Data Storage Capacity** – Each of the technologies identified in this risk are required to ingest gigabytes of data every hour and store the data either in temporary or persistent storage. With current technology, the technical risk is minimal for persistent storage systems (there are commercial cloud-based products that provide the functionality). However, for edge devices such as modems and mobile phones, the storage is limited.	Low
R-11	ET-3, ET-5, ET-15, ET-16, ET-17	**Location and Orientation Accuracy** – Location and orientation (i.e. user's direction of travel) accuracy is required to support several ST-CTN system functions. Currently, CV deployments throughout the country have had challenges with location and orientation data and have sought ways to improve the accuracy of the data through various methods.	Medium

4.2. Mitigating Risk

For each of the "High" impact risks identified in **Section 4.1**, **Table 22** describes the risk probability or the likelihood of the risk occurring (low, medium, or high) and the mitigation strategy that will be used to reduce the risk. The risk probability levels rely on the occurrence of temporal or persistent external events related to environmental conditions, or technology disruptions / degradation. The qualitative assessments have been associated with a quantitative score to be consistent with the ST-CTN project risk registry, i.e., a risk probability level of high is equivalent to a score of 5.

- **Low (1)**: risk is unlikely to occur and, should it happen, is expected to have a temporary occurrence.
- **Medium (3)**: risk is somewhat likely to occur and indicates persistent occurrence, with partial operational impacts.
- **High (5)**: risk is likely to occur and indicates persistent occurrence, impacting critical system functions and has the possibility of impacting safety.

Table 22. High-Impact Risk Mitigation Plans

Risk ID	Risk Probability	Mitigation Plan
R-1	Medium	**Resources** – The ST-CTN project team will continue to work diligently through Phase 1, concept development, to understand, define, develop, and document the anticipated schedule, budget, and staff hours required to design, deploy, operate, and maintain the ST-CTN system. The ST-CTN project team will implement the following activities to mitigate potential resource limitations: • Clearly define Phase 2 and Phase 3 SyRS with partner concurrence. • Clearly define Phase 2 and Phase 3 partner roles and responsibilities within the framework of system requirements. • Develop Phase 2 and Phase 3 schedules with partner concurrence. • Develop Phase 2 and Phase 3 budgets with partner concurrence. • Monitor, track, and report resources throughout Phase 2 and Phase 3 to identify any potential issues early so that they may be addressed efficiently.

Risk ID	Risk Probability	Mitigation Plan
R-2	Medium	• **Subsystem Deployment Interdependencies** – The ST-CTN project team is comprised of partners representing each of the subsystems that will be leveraged to support the ST-CTN system. These representatives will be responsible for tracking and reporting subsystem – CV and ATL RIDES – project status and anticipated concerns. During Phase 2 and Phase 3, the ST-CTN project team will hold bi-monthly project team meetings in which the status of subsystem deployments will be reported such that any risks to the ST-CTN system deployment will be communicated with the team. It will be the responsibility of the team to determine how to offer subsystem support or modify ST-CTN system schedule or dependencies to address the issues.
R-4	Low	**Integration Challenges (Existing Technologies)** – Mitigating risks associated with integrating existing technologies will require concerted coordination. The following integration leads have been assigned for each existing ET anticipated to have potential integration challenges: • ET-1 – GCDOT • ET-2 – GA Tech • ET-3 – GDOT Each integration lead will update the project team on status and issues related to integration during ST-CTN bi-monthly project meetings. The ST-CTN project team will look for ways to provide additional resources or technical support to resolve issues before impact is realized on the ST-CTN system deployment.

Risk ID	Risk Probability	Mitigation Plan
R-5	Medium	**Integration Challenges (New Technologies)** – Mitigating risks associated with integrating new technologies will require concerted coordination and persistence. The following integration leads have been assigned for each new ET anticipated to have potential integration challenges: • ET-5 – GCT • ET-6 – GCT • ET-7 – GA Tech • ET-12 – GA Tech Each integration lead will update the project team on status and issues related to integration during ST-CTN bi-monthly project meetings. The ST-CTN project team will look for ways to provide additional resources or technical support to resolve issues before impact is realized on the ST-CTN system deployment. Additionally, given the limitation and risk associated with ET-6, the integration challenges may negate the system benefits for this project.
R-6	Low	**Varied Institutional Security and Privacy Requirements** – Mitigating varied institutional security and privacy requirements will require early and focused coordination. The ST-CTN project team will address this within the development of the SyRS. System requirements pertaining to the reconciliation of varied security and privacy requirements will be developed and vetted by system developers and IOOs.

Appendix A. Acronyms

ABM – activity-based travel demand model

ADA – Americans with Disabilities Act

API – application programming interface

ARC – Atlanta Regional Commission

ARPA-E – Advanced Research Projects Agency-Energy

ATIS – Advanced Traveler Information System

ATL – Atlanta-Region Transit Link Authority

ATL RIDES – Atlanta-Region Rider Information and Data Evaluation System

ATMS – Advanced Traffic Management System

AVL – automatic vehicle location

BLE – Bluetooth Low Energy

BSM – basic safety message

CAD – computer aided dispatch

ConOps – Concept of Operations

COTS - commercial off-the-shelf

CV – connected vehicle

CV1K – Regional Connected Vehicle Infrastructure Deployment Program

CVTMP – Connected Vehicle Technology Master Plan

C-V2X – Cellular – Vehicle to Everything

DMP – Data Management Plan

DOE – Department of Energy

DRSB – Deployment Readiness Summary Briefing

EMT – Executive Management Team

ET – Enabling Technology

ETRA – Enabling Technology Readiness Assessment

FHWA – Federal Highway Administration

FTA – Federal Transit Administration

GA Tech – Georgia Institute of Technology

GCT – Gwinnett County Transit

GCDOT – Gwinnett County Department of Transportation

GDOT – Georgia Department of Transportation

GOSystems – GO Systems and Solutions

GPS – global positioning system

GTFS – General Transit Feed Specification

ICTDP – Integrated Complete Trip Deployment Plan

IOO – infrastructure owner/operator

ITS – Intelligent Transportation Systems

JPO – Joint Program Office

JSON – JavaScript Object Notation

KHA – Kimley-Horn and Associates, Inc.

LEP – limited English proficiency

MAP - MapData

MARTA – Metropolitan Atlanta Regional Transit Authority

MDT – mobile data terminal

MU – mobile unit

OBU – onboard unit

OSM – Open Street Map

OST – Office of the Secretary

OTP – Open Trip Planner

P&S – publish and subscribe

PED-SIG – Mobile Accessible Pedestrian Signal System

PMESP – Performance Measurement and Evaluation Support Plan

PSM – personal safety message

QA / QC – quality assurance / quality control

QR – quick response

RSU – roadside unit

SDK – software development kit

SEMP – Systems Engineering Management Plan

SILCGA – Statewide Independent Living Council of Georgia

SMP – Safety Management Plan

SMUG – Secure Mobile Unit Gateway

SPaT – signal phasing and timing

SRM – signal request message

SRTA – State Road and Tollway Authority

SSM – signal status message

ST-CTN – Safe Trips in a Connected Transportation Network

STM – space time memory

SyRS – System Requirements Specification

TRL – Technology Readiness Level

TRLG – Technology Readiness Level Guidebook

TSP – transit signal priority

TSR – transit stop request

USDOT – United States Department of Transportation

Appendix B. Glossary

Advanced Traffic Management System (ATMS) – a system that focuses on reducing congestion on roads through traffic flow sensors, data analysis, and communication technologies. The ATMS is able to centralize traffic monitoring, send updates to dynamic message signs, traffic signals or ramp meters, send public transportation updates, and perform predictive traffic modeling among other capabilities. [ATMS]

Advanced Traveler Information System (ATIS) – a system that collects, aggregates and disseminates transportation information, such as traffic, transit, weather, and connected vehicle data. This data is aggregate into data environments allowing for the dissemination of this information to travelers via mobile devices. [ATIS]

Americans with Disability Act (ADA) – An act to “provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities.” The act provides enforceable standards to address discrimination against individuals with disabilities and requires public facilities to be readily accessible and usable by individuals with disabilities [ADA].

Application Programming Interface (API) – Enables companies to make available the data of their products and services to external developers and business partners. This allows multiple services and products from different companies to communicate and leverage each other’s data for improved collaboration, innovation, and added security [API].

Automatic vehicle location (AVL) – system used by transport operators to provide an information channel between vehicles, operation control centers and real-time passenger information systems which allow for real-time tracking of vehicles [AVL]

Basic Safety Message (BSM) – Data content that is broadcasted through V2V or V2I at a 10 Hz frequency. The data elements are vehicle position (latitude, longitude, elevation) and motion (heading, speed, acceleration). [CAV]

Computer aided dispatch (CAD) – software used to monitor transit operations and help with the management of transit operations. The software takes in information on transit routes, schedules, trip orders and vehicle assignments so that dispatchers are aware of their agency’s transit vehicles’ locations. [CAD]

Connected Vehicle (CV) – A vehicle (car, truck, bus, etc.) that is equipped with a wireless communication device (1). A CV uses any of the available wireless communication technologies to communicate with other cars on the road (vehicle-to-vehicle [V2V]), roadside infrastructure (vehicle-to-infrastructure [V2I]), and other travelers and the cloud. [CAV]

Connected Vehicle Technology Master Plan (CVTMP) – a plan that sets out to develop and improve economic viability and quality of life, address the needs and challenges to motorized and non-motorized modes, establish guidelines for deploying technology, and have broad applicability to Gwinnett, other local jurisdictions, and across the state—to set the standard for implementing CVs. [ConOps]

General Transit Feed Specification (GTFS) – A data specification that allows public transit agencies to publish their data to be consumed by a variety of transit-related applications. This data includes schedule, fare, and vehicle position which can be used to predict arrival times and display real-time information [GTFS].

Mobile Accessible Pedestrian Signal System (PED-SIG) - A mobile application system that exchanges information between roadside or intersection sensors and mobile devices carried by a pedestrian. The system is used to inform impaired pedestrians when to begin traversing a crosswalk and how to remain within the crosswalk. [CAV]

Onboard Unit (OBU) – An ITS related hardware that performs the data exchange between the infrastructure and a vehicle and installed in a vehicle (includes an after-market device). An OBU may contain applications that process the data received from the infrastructure and other sources such as another OBU. [CI]

Publish and subscribe (P&S) – describes the method of message or data transfer where data is published to a specified location by a host and is requested by users in the form of a subscription to the stream.

Personal Safety Message (PSM) – A data broadcast by a vulnerable road user (such as pedestrians) to announce their presence to approaching vehicles. [CAV]

Regional Connected Vehicle Infrastructure Deployment Program (CV1K) – the program deploying interoperable CV technologies at signalized intersection through the Atlanta region using Dedicated Short-Range Communications (DSRC) and C-V2X technologies to deliver safety and mobility-based applications. [ConOps]

Roadside Unit (RSU) – A transportation field device that performs the data exchange between OBUs, MUs, and other infrastructure elements. [CI]

Signal Phase and Timing (SPaT) – The signal state of the intersection and how long this state will persist for each approach and lane that is active, according to the SPaT Benefits Report. The SPaT message sends the current state of each phase, with all-red intervals not transmitted. Movements are given to specific lanes and approaches by use of the lane numbers present in the message. In a connected vehicle environment, the message is sent from the roadway infrastructure to approaching vehicles. [CAV]

Secure Mobile Unit Gateway (SMUG) – serves as a secure means of exchanging information between a mobile unit (or proxy such as the ATL RIDES subsystem) and the CV environment. The MU Gateway serves to provide authenticated access, validate messages, transform and direct the messages to the appropriate destination. [ConOps]

Transit Signal Priority (TSP) – A part of a signal system that allows transit agencies to manage service by prioritizes buses and granting their right of way based on schedule adherence or passenger loads. [CAV]

Appendix C. Enabling Technology-System Needs Matrix

The following table provides traceability between each ET and associated system need. ET-2 and ET-4 are no longer relevant to the project and have been removed.

Table 23. Enabling Technology – System Needs Matrix

ET / SY ID	ET / System Need Statement
ET-1	**Secure Mobile Unit Gateway (SMUG)**
CV-SY-5.1	The system needs to connect travelers to the connected infrastructure to increase safety.
ET-3	**Mobile Accessible Pedestrian Application (PEDSIG)**
IC-SY-4.1	The system needs to connect to traffic signal system infrastructure to enable travelers to activate crosswalk signals using hands-free method, or automatically using their trip plan and location so that the traveler is able to complete their trip based on their preferences and abilities.
IC-SY-4.2	The system needs to connect to traffic signal system infrastructure to enable travelers to activate crosswalk signals using a hands-free method, or automatically using their trip plan and location so that the traveler is able to complete their trip based on their preferences and abilities.
CV-SY-5.1.2	The system needs to detect that a traveler has exited the intersection to support pedestrian safety applications.
ET-5	**Transit Connection Protection (Transit Stop Request (TSR))**
TT-SY-3.1	The system needs to provide a method for a traveler to send a stop request to an approaching transit vehicle. The stop request may also identify special needs of the traveler.
TT-SY-3.2	The system needs to confirm receipt and status of the request for a transit stop request so that the traveler knows that their request has been received by the system.
ET-6	**Transit Next Stop Request (in vehicle)**
BT-SY-2.2	The ATL RIDES Mobile App needs to be capable of providing hands-free, turn-by-turn directions based on user preferences and abilities to meet user needs.

ET / SY ID	ET / System Need Statement
TT-SY-3.1	The system needs to provide a method for a traveler to send a stop request to an approaching transit vehicle. The stop request may also identify special needs of the traveler.
TT-SY-3.2	The system needs to confirm receipt and status of the request for a transit stop request so that the traveler knows that their request has been received by the system.
ET-7	**Network Impedance API**
BT-SY-2.1.3	STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., Sidewalk Sim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes.
ET-8	**STM Composite/Architecture - Network Generation and Scalability**
BT-SY-2.1	The complete trip system functions (STM and ATL RIDES) need to be scalable to generate and accommodate multiple personalized trip plans and journeys for travelers simultaneously in order to be reliable and responsive to traveler requests and preferences.
PT-SY-1.3	The system needs to generate a framework to transform values assigned to travel preferences into impedance values for simulation models (e.g., Sidewalk Sim).
FT-SY-8.1	The system needs to allow for future scalability or development in order to address user needs that are not within the scope of this project and will not be implemented in the initial roll out.
FT-SY-8.1.1	The system needs to be scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be needed to buy transit tickets or passes from public agencies.
FT-SY-8.1.2	The system needs to be scalable such that other geographic areas may be included in the future.
FT-SY-8.1.5	The system needs to be scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be mobility service access rights from private sector agencies such as bikeshare, ridehailing, microtransit services or others.
ET-9	**STM Simulator - Integrate New Features into Sidewalk Sim**

ET / SY ID	ET / System Need Statement
NV-SY-6.1	The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator-escalator outages) to ensure accuracy in the accessibility of routes.
ET-10	**STM Impact Assessment and Network Edge-Cost Analysis Engine Upgrade**
PT-SY-1.3	The system needs to generate a framework to transform values assigned to travel preferences into impedance values for simulation models (e.g., Sidewalk Sim).
NV-SY-6.1	The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator-escalator outages) to ensure accuracy in the accessibility of routes.
ET-11	**STM Operational and Prediction Analysis Engine Trip Compliance Analysis**
BT-SY-2.1.3	STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., Sidewalk Sim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes.
PT-SY-1.3	The system needs to generate a framework to transform values assigned to travel preferences into impedance values for simulation models (e.g., Sidewalk Sim).
ET-12	**STM-ATL RIDES Trip and Infrastructure Feedback (Exchange #4)**
RP-SY-7.2	The system needs to collect user input (using crowdsourcing methods) about disruptions and obstructions to their travel during or after their travel.
RP-SY-7.3	The system needs to provide anonymized information about trip performance to the performance monitoring module (in the STM subsystem) that details traveler behavior to help improve trip plan customization for users.
ET-13	**STM Dynamic Data Broke to Ingest New Data Sources**
BT-SY-2.1.3	STM needs to respond and generate updates based on the ATL RIDES routing engine needs to the predictive networks (e.g., Sidewalk Sim), and produce an appropriately formatted network that can be ingested for trip planning and journeying purposes.
NV-SY-6.1	The system needs to ingest static and real-time data about indoor and outdoor assets and conditions (e.g., sidewalk blockages, elevator-escalator outages) to ensure accuracy in the accessibility of routes.

ET / SY ID	ET / System Need Statement
FT-SY-8.1.1	The system needs to scalable to accommodate future growth, modifications, or integration with multiple services, including those that may be needed to buy transit tickets or passes from public agencies.
ET-14	**STM Performance Monitoring Dashboard PMESP Implementation**
RP-SY-7.3	The system needs to provide anonymized information about trip performance to the performance monitoring module (in the STM subsystem) that details traveler behavior to help improve trip plan customization for users.
ET-15	**ATL RIDES Turn-By-Turn Direction Support and Indoor Navigation**
BT-SY-2.2	The ATL RIDES Mobile App needs to be capable of providing hands-free, turn-by-turn directions based on user preferences and abilities to meet user needs.
BT-SY-2.3	The system needs to be compatible with open standards that are embedded or used in devices including mobile phones and connected assistive devices.
BT-SY-2.6	The system needs to activate automated messages and alerts, as well as re-routing based on real-time information consistent with the traveler's preferences while the traveler is executing their travel.
NV-SY-6.2	The system needs to interface with facility or third-party communications assets using protocols available on smartphones (e.g., near-field communication (NFC), Bluetooth, Wi-Fi) and also use standardized navigation or wayfinding messages to communicate with travelers.
ET-16	**ATL RIDES Notifications and Event Triggers**
PT-SY-1.4	The system needs to allow travelers to customize the UI of the application based on their abilities or preferences.
BT-SY-2.4	The system needs to be designed such that travelers will be able to customize how notifications are received based on their abilities or preferences.
ET-17	**ATL RIDES Trigger Settings**
TT-SY-3.1	The system needs to provide a method for a traveler to send a stop request to an approaching transit vehicle. The stop request may also identify special needs of the traveler.
IC-SY-4.1	The system needs to connect to traffic signal system infrastructure to enable travelers to activate crosswalk signals using hands-free method, or automatically using their trip plan and location so that the traveler is able to complete their trip based on.

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