# TRX Systems Smart Wayfinding and Navigation System Using High Accuracy 3D Location Technology Final Report

Accessible Transportation Technologies Research Initiative (ATTRI)

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#### 16. Abstract

TRX developed a NEON® Smart Wayfinding and Navigation (SWaN) service that delivers the underlying location and routing capabilities required to allow application developers to provide travelers with real-time location and en-route assistance and situational awareness, including within complex urban transport structures. These core indoor location and routing capabilities enable application developers to better support safe independent travel for people with a diverse set of abilities. SWaN is part of the USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) and complement's the ATTRI Complete Trip initiative, supporting assistive Wayfinding and Navigation in challenging indoor environments. During this project, TRX extended an existing baseline location service (NEON) to support the requirements of accessible travelers. Key tasks included development of venue mapping and route creation tools, delivery of infrastructure-free and infrastructure-based location capabilities, and support for determination of a route through a complex transit structure with accessible constraints. TRX developed a routing API for complex transport structures along with the tools required by venue owners to model their building (incorporate building information, define possible routes, and define points of interest). A demonstration user interface was made available to support validation of the underlying functionality and integration tools have been provided to support easy integration with SWaN services. A developer portal that supports the API was launched including access to documentation, javadocs, and sample application code. The core innovation was the development of a navigation and wayfinding mobile service with open APIs for application developers delivering localization, orientation, waypoint navigation, and route guidance. This document summarizes the developments and benchmark testing performed during this two-year project, including successful testing and validation in complex transit hubs in the DC metro.

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# **Executive Summary**

TRX developed a Smart Wayfinding and Navigation (SWaN) service that delivers accessible map and route creation tools for transit agencies (venue owners) and path planning and routing capabilities for application developers. This service provides the tools required by application developers to develop applications that provide travelers with real-time location, en-route assistance and situational awareness, including within complex urban transport structures. Today's transit structures offer basic maps, limited assistive routing information, and there are no tools available to assist with routing for those that might have specific accessibility needs.

SWaN is part of the USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) and complement's the ATTRI Complete Trip initiative, supporting assistive Wayfinding and Navigation in challenging indoor environments.

SWaN is an extension of an existing mobile location service – the NEON service – that makes available for application providers tools that allow them to deliver navigation and mapping services for users with specific accessibility needs. Accessible features were added to this existing service that could be made available to application developers focused on accessible application creation. As part of the overall SWaN capability set, PC-based route creation tools were developed to allow transit venue managers and operators to create and add route graphs and accessibility information to facility maps. These maps and routing graphs are then made available to application developers through mobile application developer interfaces (APIs).

This document summarizes the developments and benchmark testing performed during this two-year project, including successful testing and validation in complex transit hubs in the DC metro.

## **ATTRI Program Background**

The USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) is a joint USDOT initiative, co-led by the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), and Intelligent Transportation Systems Joint Program Office (ITS JPO), with support from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR), and other federal partners. The ATTRI Program is leading efforts to develop and implement transformative applications to improve mobility options for all travelers, particularly those with disabilities. ATTRI research focuses on removing barriers to transportation for people with visual, hearing, cognitive, and mobility disabilities. Emerging technologies and creative service models funded by ATTRI will offer all Americans enhanced travel choices and accessibility at levels once only imagined. The USDOT has awarded application development funding for Wayfinding and Navigation, Pre-trip Concierge & Virtualization, Safe Intersection Crossing with NIDILLR awarding a grant in the Robotics and Automation technology area. Working together, the four technology areas will provide the basis for an accessible transportation network that is far more economical, expansive, and welcoming than we have now, which is of increasing importance not only to travelers with disabilities, but to all travelers in the United States.

## **TRX SWaN Program - Support of the Complete Trip**

The TRX ATTRI SWaN program fits within the Wayfinding and Navigation topic area. The goals of the project were to develop and deliver a mobile location and routing service that supports application developers who are building applications that offer travelers real-time location, en-route assistance and situational awareness indoors and out so they can safely navigate while traveling independently. The core innovation is background mobile service with open APIs delivering routing, user location, orientation, waypoint navigation, and real-time route guidance within complex transit facilities. Developers can use the SWaN background mobile service APIs to develop path planning and wayfinding applications for travelers with diverse needs. SWaN is delivered as a background application that runs on standard smartphones and smartphones paired with a wearable accessory. Application developers' interface to (and activate) the background application through use of the SWaN APIs.

SWaN delivers location and routing in the "last mile" of the ATTRI complete trip. For example, in Step 2 of Figure 1: ATTRI Complete Trip, SWaN will allow a user to navigate independently through a transit station, from the front door through the transit station to the train or subway platform. In Step 5, SWaN will continue to support the person traveling all the way through to their destination (doctor's office or other office to which they are headed). By enabling people to independently route through transport structures, public buildings and recreational centers, and other complex buildings, a key gap in the complete trip travel chain will be closed.



# After his doctor's appointment, Andy decides to take a spontaneous trip to meet a friend at a coffee shop in an

THE COMPLETE TRIP

Source: DOT- https://www.its.dot.gov/research areas/attri/index.htm

#### Figure 1: ATTRI Complete Trip

# **Underlying Technology**

A key aspect of the TRX SWaN project is the ability to deliver location and routing with and without installing dense network or beacon infrastructure (unrealistic in existing complex transit hubs).

The SWaN mobile application uses data from small sensors (available in a specialized accessory device that can pair with a mobile phone, and also available in some models of phones themselves) to estimate the user location as they move through a building. Using small sensors in a wearable device allows for navigation without infrastructure; however, the sensors in these devices are subject to errors over time. By knowing the map of the building – and by interfacing with optional beacons – the wearable sensors are "assisted" and the accuracy required to support accessible navigation and routing is attained.

To deliver the accuracy required for assistive routing, it is necessary to adjust the service precision and accuracy in areas where the highest accuracy is required. This is accomplished by making it possible to add beacons in areas where the highest accuracy is required (e.g., near ticket booths, turnstiles, or elevators, for example).

PC-based tools are provided to allow route graphs - i.e., all the available paths through a transit facility to the destination (e.g., train, metro, or plane) - to be defined and modified by venue owners and transit agencies, including addition of accessible attributes on each route segment (such as whether carpeted, includes stairs, crowded, etc.) layers well as ability to take easily take routes "out of service".

The project complements developments in the commercial sector, benefiting from all innovations on standard mobile devices and <u>extending these with a specific focus on independent travel for individuals</u> <u>with disabilities</u>. An open API is supported allowing position data to be provided by external systems; this means SWaN will evolve naturally as new location, mapping, and routing technologies are introduced.

## **Project Scope and Developments**

In this project, TRX has extended an existing baseline location service (NEON) to support the requirements of accessible travelers. Key accomplishments included:

- Support for routing in complex structures, including overlapping above and underground structures typical of transportation hubs. Development was performed to deliver routing (i.e., to support applications delivering accessible navigation) and to use planned routes to improve location accuracy within these structures.
- Extension of venue mapping and routing tools that allow transit agencies to model 3D routes through complex buildings. Route creation tools were made available to allow definition of feasible routes from any point of interest to any other point of interest, and accessibility ratings and features can be defined for each route segment.
- Development and documentation of open APIs for use by mobile application developers that allow
  determination of a route through a complex structure and between points of interest with support for
  accessible constraints. A developer portal was implemented to support application developer use of routing
  APIs (<u>https://docs.trxsystems.com/android-api/routing-api/</u>). Hackathons were performed to ensure the
  APIs and developer portal met application developer needs.

Developer test and validation performed by the UMBC Human Centered Computing group and developers at the hackathon organized by UMBC HCC validated the solution and helped to increase maturity and usability.

### **Summary and Project Achievements**

During this program, TRX developed a Smart Wayfinding and Navigation service that delivers path planning and routing capabilities for application developers. The focus of the program was to provide tools required by venue owners to allow them to establish route graphs and by application developers to allow them to establish a range of independent travel applications. Complemented by an existing mobile location and mapping service – the TRX NEON service - these tools:

- Support development of applications that deliver navigation, mapping, and routing services for users with specific accessibility needs.
- Map complex transit hubs including development of 3D model of routes through the structures. Mapping is performed by venue owners.
- Support identification of points of interest within complex transit hubs that may be useful to path planning and real-time routing. Venue owners can define points of interest which are made available through the routing Application Programming Interfaces (APIs).
- Provide mobile APIs that deliver real-time location within complex transit hubs, including location within 3D.
- Provide mobile APIs and sample apps that deliver en-route assistance and situational awareness for users as they transit through complex structures.

As part of the overall SWaN capability set, PC-based route creation tools were developed to allow transit venue managers and operators to create and add route graphs and accessibility information to facility maps. These maps and routing graphs are then made available to application developers through mobile APIs. Testing with application developers and within complex transit hubs demonstrated the ability to support accessible routing using these tools. Documentation was expanded and sample apps for developers were enhanced. Feasibility of implementation and functionality in a complex transit hub was assessed.

The SWaN program delivered a significant element of the end-to-end trip – navigation and accessible routing within complex transit hubs. However, there are many more elements required to support fully accessible independent travel for users of all abilities. A beneficial next step would be to implement a prototype in a key metro area – supporting accessible navigation from user residence over relevant transit nodes and through a key transit hub. Development of this type of a prototype complete trip application would prove out the utility of the technology supporting each of the trip segments, mature the underlying accessible navigation, routing, and API technologies through actual deployment and use, and connect each sement with a top level application supporting the end to end planning and navigation functions required.

# **Chapter 1. Introduction**

TRX developed a Smart Wayfinding and Navigation (SWaN) mobile application service that delivers the accessible routing capabilities required to allow end user application developers to provide travelers with pre-trip planning and navigation services, including within complex urban transport structures. PC-based mapping tools were developed to allow transit venue managers and operators to add accessible information to transit facility maps and to define routes through facilities with the information required to understand the accessible characteristics of each route. The SWaN service is delivered as a background mobile location service with accessible indoor routing services that enable application developers to better support safe independent travel for travelers with a diverse set of abilities. This document summarizes the developments and benchmark testing performed during the project.

# Chapter 2. Background and Support of the Complete Trip

# **ATTRI Program Background**

The USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) is a joint USDOT initiative, co-led by the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), and Intelligent Transportation Systems Joint Program Office (ITS JPO), with support from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR), and other federal partners. The ATTRI Program is leading efforts to develop and implement transformative applications to improve mobility options for all travelers, particularly those with disabilities. With nearly 20 percent of the U.S. population comprising individuals with disabilities, and other demographic trends such as the increasing number of older Americans, USDOT is seeking to expand innovative travel options. ATTRI research focuses on removing barriers to transportation for people with visual, hearing, cognitive, and mobility disabilities. Emerging technologies and creative service models funded by ATTRI will offer all Americans enhanced travel choices and accessibility at levels once only imagined. The USDOT has awarded application development funding for Wayfinding and Navigation, Pre-trip Concierge & Virtualization, Safe Intersection Crossing with NIDILLR awarding a grant in the Robotics and Automation technology area. Working together, the four technology areas will provide the basis for an accessible transportation network that is far more economical, expansive, and welcoming than we have now, which is of increasing importance not only to travelers with disabilities, but to all travelers in the United States.

# Goals – TRX ATTRI SWaN Program

The goals of the TRX ATTRI SWaN project were to develop and deliver a mobile application service (a background application) that provides the tools required by mobile developers to allow them to deliver end user applications (i.e., front end applications that provider the interactive application for the end user). The TRX SWaN application service is delivered as a mobile application that runs in the background, without an interface to the end user of the device. The SWaN mobile application service supports development of path planning and routing applications as well as end-user assistive navigation applications that can deliver wayfinding for travelers with diverse needs. SWaN runs as a background application on standard smartphones and smartphones paired with a wearable accessory. Paired with the SWaN mobile APIs are PC-based tools for transit agencies and venue owners that allow them to map their facilities and establish 3D route graphs with the accessibility criteria required to allow path planning for people with a range of accessibility needs.

## The Last Mile

SWaN delivers location and routing in the "last mile" of the ATTRI complete trip. For example, in Step 2 of Figure 2, SWaN will allow a user to navigate independently through a transit station, from the front door through the transit station to the train or subway platform. In Step 5, the capabilities SWaN delivers enables

application developers to deliver applications that continue to support the person traveling all the way through to their destination (doctor's office or other office to which they are headed). By supporting development of accessible navigation applications that enable people to independently route through transport structures, public buildings and recreational centers, and other complex buildings, a key gap in the complete trip travel chain will be closed.



Source: DOT- https://www.its.dot.gov/research\_areas/attri/index.htm

#### Figure 2: ATTRI Complete Trip

An important aspect of the TRX SWaN project is the ability to deliver location and routing with and without infrastructure, and to be able to adjust the service capabilities (accuracy, precision) with the addition of a small number of location constraints (e.g., beacons) in specific areas. At the core of the application, inertial sensors such as accelerometers, gyroscopes, magnetometers and pressure sensors are used to estimate the user path. This allows for navigation without infrastructure; however, these sensors are subject to errors over time. Map and beacon technologies are used to update user location when the users pass by such known map or beacon features. The use of an optional accessory and map features allows a dramatic reduction in the number of beacons required within large complex transit environments to meet user and application accuracy needs.

Route graphs can be defined and modified by venue owners and transit agencies, including addition of accessible attributes on each route segment as well as ability to take easily take routes "out of service".

Venue owners can also add navigation assistance information that supports more accurate localization, including performing a "preplanning" function that establishes maps of WiFi throughout the transit hub, and installing beacons in select areas that improve localization accuracy (e.g., by elevators, turnstiles, stairwells, ticket booths).

The project complements developments in the commercial sector, benefiting from all innovations on standard mobile devices and <u>extending these with a specific focus on independent travel for individuals</u> <u>with disabilities</u>. An open API is supported allowing third party location constraints to be provided, which means SWaN will evolve naturally as new technologies are introduced (e.g., Wi-Fi time of flight, Ultrawideband radio frequency within mobile devices).

## Benefits of the TRX Approach

The location and routing capabilities are implemented as a background mobile application service – i.e., a background service that can be used by developers of assistive end user applications. This background mobile application service acts as a layer on top of commercial mobile technology. Commercial mobile technology provides GPS for example, but may not deliver an accurate location on a metro platform. The SWaN background mobile application service will use GPS when it is available from the commercial mobile device and will continue to deliver location when GPS is unavailable (e.g., when the user goes indoors). When application developers use the APIs from the SWaN background application, they attain an additional layer of capability provides:

- Ubiquitous location and navigation capabilities in every venue, including complex transportation hubs that have overlapping above and below ground elements
- Precise navigation exactly where needed, while supporting comprehensive infrastructure-free location throughout areas where location does not need to be as precise. For example, it is possible to deliver meter-level accuracy at certain points, such as stairwells, elevators, ticket booths, turnstiles, for users that may need this very high accuracy to make decisions at these points.
- Routing that supports the independent travel requirements of users with a range of abilities, allowing applications to request routes based on specific user group priorities.

The SWaN background mobile application service enables delivery of innovative accessible location, wayfinding, and navigation applications to be developed for a diverse user community.

Tools are provided for venue owners that give them control over the mapping within their facility and allow them to create and modify accessible route graphs through the transit hubs. This includes definition of routes, establishment of route accessibility criteria, definition of points of interest, and addition of navigation assistance information (such as WiFi maps as well as BLE and UWB beacons in choke points or areas where the highest accuracy is required).

The SWaN APIs, developer program, and hackathon efforts support the development of an ecosystem of venue owners, transit organizations and application developers focused on expanding independent travel for all people. The expected impact will be improved mobility options for people with a broad range of navigation capabilities, enabling increased safety during independent travel within complex transit and other indoor or underground facilities.

# **Chapter 3. System Concept of Operations**

The following is information designed to provide background and context for the developments performed within this project.

# **Baseline System Architecture**

The development of the SWaN System began with a baseline indoor localization system called NEON. The TRX NEON system uses existing commercial mobile device platforms, navigation and mapping algorithms and optional wearable accessories whose development has been supported by NSF, DHS, DARPA, US Army and prior ATTRI funding.



Source: TRX Systems, June 15, 2018

#### Figure 3: Baseline System - NEON Personnel Tracker Application with optional NEON Tracking Unit (Wearable Accessory)

NEON delivers location indoors and in areas without reliable access to location services. When outside, mobile devices use GPS to provide location. GPS is a satellite service that requires a clear view of the sky to deliver accurate location. Once inside, GPS services are unavailable and WiFi signals are often used to deliver location. However, unless dense infrastructure is deployed throughout a venue, WiFi cannot provide reliable location; even where dense infrastructure is deployed, WiFi is not accurate enough for many assistive routing applications.

NEON starts with commercial mobile location services (i.e., those that are provided by standard commercial devices) and adds accuracy using sensors within a wearable accessory device (or optionally, where phones have the quality of sensors required, using sensors within a mobile phone itself), known map data (e.g., venue map), and optional commercial beacons. Within this project, TRX has enhanced the existing baseline location and mapping solution with support for routing through complex overlapping structures

(typical of navigation hubs), provided PC-based tools for creating route graphs and flexible route guidance, and used integrated BLE and highly accurate UWB sensors to support delivery of higher accuracy where it may be required (e.g., where users have a task to do, such as purchasing a ticket, or a decision to make, such as going down a stairwell).

### **Services Supported**

TRX has developed a routing API for mobile application developers to deliver path planning and navigation assistance within complex transport structures along with the tools required by venue owners to model their building (incorporate building information and define possible routes). A demonstration user interface has been made available to support validation of the underlying functionality and integration tools have been provided to enable easy integration with SWaN services.

The SWaN service leverages available existing technologies: SWaN runs on a background application service on standard Android smartphones paired with a small wearable tracking accessory; SWaN may also run on a background application service on higher end smartphones (those that support Android "Hi-Fi" sensors - https://developer.android.com/guide/topics/sensors/sensors\_overview).

Services delivered by SWaN include:

Location Service	The SWaN location service delivers real-time location for the end user device.
Routing Service	The SWaN routing service is the underlying service that delivers routing based on the criteria requested by the end user application.
Mapping Service	The mapping service is the underlying service that maintains and delivers map data. In addition to the NEON Location Assistance map data, multiple 3rd party map services are required to acquire satellite, terrain, building, floor plan, and point of interest data. <u>SWaN uses mapping databases and delivers tools to create building outlines. End user applications will query third party map tools in addition to receiving building information from SWaN.</u>

Table 1:	Summary	of SWaN	Services
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TRX developed a prototype app ("SWaN App") to validate the routing API and has developed the documentation required to make the location and routing services, and associated APIs, available to third party application developers.

The NEON SWaN APIs are being made accessible broadly to application developers, allowing for immediate use by developers interested in extending the solution capabilities with targeted applications. *Making the NEON SWaN Service available to an ecosystem of developers will ensure scalable feedback* on the service capabilities and will support delivery of accessible navigation apps for those of all abilities.

### **User Groups Supported**

The hierarchy of users and customers of the SWaN service is as follows:

End User	The "end user" is the person navigating, and will include people with diverse needs, including those with mobility <sup>1</sup> , cognitive, vision, hearing, and memory disabilities. These needs are different end user "contexts" - i.e., the user has a vision disability, or a cognitive disability, and that context will influence their requirements for applications that support them with independent travel. The end user is the ultimate customer but does not directly interface to SWaN <sup>2</sup> .
Application Provider	The application developer is the direct interface to the end user and the customer of SWaN. The application developer supports customization for a specific user group and is also the "personalization" engine for the user. <u>The application provider is a customer of SWaN location and routing services.</u> <u>Application providers will often also populate and query mapping and POI or notes databases directly.</u>
Venue Manager	Unique to indoor localization, the venue manager will be involved with defining points of interest and accessible routes. <u>The venue manager is a customer of SWaN and is a required participant in support of SWaN service delivery.</u>

#### Table 2: SWaN Users and Customers

Other users include smart wearables, next gen robotic, and AI tools that could connect with the SWaN API or embed SWaN algorithms. No specific new features are being added within this project to support these users; however, TRX is separately structuring the software for portability, is integrating with third party wearable companies, and has developed an API that takes in location input (simplifying integration with third party location aware applications and systems).

<sup>&</sup>lt;sup>1</sup> Transportation venues and public buildings will require substantial infrastructure to provide highly accurate real-time location for wheelchair users. This challenge will be alleviated over time as Wi-Fi and other signals of opportunity and RF beacon technology (including both BLE and UWB) is increasingly deployed throughout such environments. It would also be possible to add a sensor to the wheelchair itself, model the wheelchair motion, and integrate this within SWaN. In this program the underlying mobile services delivered made it possible to obtain routes for wheelchair users and, with infrastructure, to deliver real-time location.

<sup>&</sup>lt;sup>2</sup> TRX has provided a demonstration SWaN app that allows testing and verification of the underlying system routing functionality but is not intended to be supplied to end users as a final, user-friendly accessible solution for navigation and routing. Source code for this app is provided to app developers to jump start development of accessible apps.

# Chapter 4. User Oriented Operational Needs

TRX organized end user requirements using the wayfinding and navigation processes defined by ATTRI in its "State of the Practice Scan" (developed by the Robotics Institute at Carnegie Mellon). This set of processes was used to organize requirements discussed with and feedback received from the National Federation of the Blind, University of Maryland Baltimore County, University of California Irvine, ATTRI program representatives, and as collected by TRX in an earlier FHWA project working focused on visually impaired user navigation.

While support for all functions are desirable, the scope of work for this project is focused on localization and orientation and path transversal and guidance functions. Supporting these functions for the application developer formed priorities in the requirements assessment performed during the project. Once an application detects transit through or proximity to a **mapped facility**<sup>3</sup>, it will be possible to access the smart wayfinding and navigation service.

## **User Needs Identification**

A qualitative interview study examining the urban navigational experiences of 27 people who identified as older adults and/or who had cognitive, visual, hearing, and/or mobility disabilities, was undertaken by researchers at the University of Maryland Baltimore County and University of California Irvine. Participants were asked to specifically reflect upon the places they go, the tools and technologies they use, strategies they employ, and features of (dis)preferred routes, and what improvements they would like to see in future technologies to aid navigation.

Route preferences and strategies were identified for each disability identity examined. Examples included calling ahead or checking floor plans online prior to making a journey to an unfamiliar environment, or if familiar to the user, checking the web site of the intended location to identify updates about construction which may impact navigation. Certain features were found to be more useful to orient position and to support navigation. Findings showed that many of these preferences and strategies were shared across disabilities (e.g., desire to avoid carpeted areas), while others diverged or were in tension (e.g., the need to avoid noisy areas while staying near main thoroughfares). Factors such as misleading accessibility information relating to the location, unexpected obstacles such as crowds blocking thoroughfares, and seasonal challenges were also found to impact the navigation process across groups.

<sup>&</sup>lt;sup>3</sup> Venue participation in the routing service will allow the application developer to access detailed routes.

## **User Needs Mapping to Navigation Functions**

With support from National Federation of the Blind (NFB), and the University of Maryland Baltimore County and University of California Irvine, a sample of the user needs was mapped to navigation processes. The user needs were not intended to be exhaustive – they formed the basis of a flexible framework that will allow support of additional user needs as these are uncovered in future Phases. As more data is collected from app developers and others, using an agile process, it will be possible to influence the protocols and architecture. Collectively, by satisfying these needs, the end user should have access to applications that improve their situational awareness and safety when traveling independently.

Wayfinding and Navigation Process	End User Needs <sup>4 5</sup>	Application Provider Needs <sup>6</sup>	Venue Manager Needs <sup>7</sup>
Familiarization	Access information required to form mental map of environment prior to committing to travel plan. Access to information including points of interest and notes.	Access point of interest data, notes data, floor plan data, shape files.	Define accessible point of interest data, floor plans, and notes.
Path Planning	<ul> <li>Plan route from origin to destination.</li> <li>Plan return trip.</li> <li>Identify route criteria ("context").</li> <li>Have the ability to add notes to their route or access previously added notes.</li> </ul>	Access detailed indoor and underground routing. Obtain routes on the basis of user context. Influence routes on the basis of user notes.	Need to be able to define feasible routes. Need to be able to define points of interest (structural or accessibility features, for example) and add notes.

 Table 3: End User Wayfinding and Navigation Process – Mapping of End User Needs

<sup>&</sup>lt;sup>4</sup> End user need summary extracted from "Accessible Transportation Technologies Research Initiative (ATTRI) State of the Practice Scan", Final Report April 10, 2017, CMU RI TR 17 15

<sup>&</sup>lt;sup>5</sup> Indirect customer of SWaN APIs. Direct customer of the Application Developer.

<sup>&</sup>lt;sup>6</sup> Direct customer of SWaN APIs.

<sup>&</sup>lt;sup>7</sup> Direct customer of the Venue Mapping and Routing Application

Wayfinding and	End User Needs	Application Provider Needs	Venue Manager Needs
Navigation Process			
Localization and Orientation	Obtain real-time location (latitude, longitude, elevation/floor) along planned path Obtain orientation (direction of motion or heading). Location accuracy dependent on user. Highest accuracy needs could be sub-meter, but many users can accept lower accuracy (and may prefer to tradeoff accuracy if they can use standard mobile device versus specialized hardware). Understand nearby points of interest (including those that would provide audio cues).	Real-time location along planned path Accurate location error estimation Real-time heading Accurate heading error estimation Nearby point of interest	N/A
Path Traversal and Guidance	Real-time assistance in following the travel plan.	Requires route between two or more locations. Must update route based on real-time location. Turn by turn route description. Needs distance remaining Needs access to route notes.	N/A

Wayfinding and Navigation Process	End User Needs	Application Provider Needs	Venue Manager Needs
Update	Must be able to update route in the event of changes in environment (e.g., exit closure, fire, broken elevator). Routes should be influenced by extended or temporary changes (construction versus elevator outage)	Needs routing to work around extended environmental closures. Needs to be able to provide "fastest exit" due to temporary environmental changes.	Ability to update closed routes.

Given the user needs, it is essential to the routing function to support attributes that can be considered when returning routes. The following points of interest categories were determined to be of interest to the user groups:

Point of Interest Category	Example	Responsibility	Vision	Mobility	Cognitive	Hearing
Structural Infrastructure	Exit/entrance, stairwell, ramps, moving walkways, elevators, escalators	Location and Routing Service	X	X	X	X
Fixed Infrastructure and Services	Security/ticket booths, water fountains, ATMs, lockers, info counters, turnstiles, power doors, revolving doors, offices, restrooms, stores, bike sharing stations	Location and Routing Service	X	X	X	X

#### Table 4: Navigable Points of Interest by User Group/Disability Served by Application

Functional Status	Closed elevator,	Location and	Х	Х	Х	Х
of Infrastructure	malfunctioning	Routing				
	escalator,	Service				
	construction zone					

Virtually all "points of interest" are required by all user groups.

In addition to the above points of interest, the following are examples of "attributes" that users may prioritize when requesting routes:

Attribute Example	Responsibility	Vision	Mobility (Incl. Elderly)	Cognitive (Incl. Elderly)	Hearing (Incl. Elderly)
Adjacent to walls	Venue Mapping Service	Х			
Well-lit area	Venue Mapping Service	X	X	Х	X
Obstacle (e.g., turnstile)	Venue Mapping Service		X		
Tactile Pavement	Venue Mapping Service	X			

 Table 5: Route Attributes by User Group/Disability Served by Application

The above list is not exhaustive. As more attributes are defined, it may be possible to divide these up into categories. However, given the specificity of the attributes, a single user group may require a set of discrete attributes to access a route that works for them.

The above was extracted from the written research and discussions with University of Maryland and NFB. The exact points of interest and route attributes were not exhaustively defined; the existence of these and the different categories provided the guidance required for systems architecture and development during the project.

# Accuracy Needs & Underlying Technology Background

User accuracy needs are highly dependent upon the user group and the capability of an individual within a user group. All users and app developers want sub-meter accuracy and perfect heading accuracy -- such precision can be delivered with sufficient infrastructure and custom accessory devices. However, users and

app developers also prefer use of a standalone mobile device, and they prefer getting a reasonably accurate solution over getting nothing at all.

Within SWaN, it is possible to demonstrate both high precision (requiring more significant infrastructure), high precision within zones (requiring infrastructure near those zones - such as near elevator entrances), and low precision (e.g., as delivered with a standard mobile device). The range of technologies being used include UWB, which, when installed frequently, can provide meter-level accuracy (this precision depends on the accuracy in which the UWB beacons are installed -- and any beacon installation inaccuracy must be added to the error budget).

Architectural approaches that support integration of UWB within displays or kiosks, within turnstiles, at elevator entrances, and near ticket windows will allow accurate distance estimation and higher accuracy near these critical transition points.

With knowledge of a planned route, heading accuracy can be increased substantially. New inputs, including those providing centimeter level accuracy, can be pulled into the system as those become available. Different user groups will require different levels of accuracy; however, the system is an aid; users must have base mobility skills to navigate. Therefore, the system will provide a benefit for users even without perfect heading accuracy (just as Google Maps provides a benefit today even when there is clear error in some of the location or heading results it returns).

User and application developer input is always "the best it can be". Some iteration will be required in working with application developers to determine how they will design applications given the accuracy that can be provided and to determine what is actually needed. And because it will be some time before infrastructure is put in place within venues, and because new signals of opportunity (new location inputs) will become available over that time as well, the ability to work with inferred data (Wi-Fi, BLE) is critical to allow near-term deployment with limited to no infrastructure for some user groups.

System accuracy will improve with feedback from location corrections and constraints. As more and more location-enabled infrastructure is deployed, higher accuracy will be achieved, thus the user groups that can be served will expand.

# **Chapter 5. System Description**

This section defines the SWaN System architecture, configuration, and operating assumptions.

## System and Software Overview

The SWaN system leverages an Android smartphone (running a location and routing service) paired with a small, wearable accessory, and operationally supports use with a cellular device alone (at a lower accuracy level). It includes a cloud-based repository of location assistance, routing, and point of interest data, and a Command Mapping Interface that supports definition of venue route maps and points of interest. A prototype accessible user interface is provided to support demonstration of the location and routing functions. New components extend the NEON Location Service architecture and components to include a cloud-based routing database, expanded point of interest and route assistance information, a prototype SWaN user interface, and enhancements to the PC-based Command App to support extended venue map and route definition capabilities (Figure 4).



Source: TRX Systems, June 15, 2018

Figure 4: SWaN System Functional Block Diagram

Figure 5 shows the Location Service architecture on the handset and accessory. The algorithms are architected to easily allow operation with a tracking accessory (or, in the future, using embedded cell phone sensors):

**NEON Sensor Hub Software:** The Sensor Hub processor resides on the NEON Tracking Accessory<sup>8</sup> (*weighing only 45g*) OR a smartphone *using only embedded sensors*. The accessory pairs with a standard smartphone to provide data from body worn lowpower sensors and time of flight ranging for improved location accuracy. The Sensor Hub software performs sensor processing using higher sample rate data, e.g., motion modeling and feature detection.

**NEON Navigation Engine Software** runs on the smartphone app processor. The implementation enables application of multi-rate and non-Gaussian measurement constraints (e.g., GPS, BLE, map feature constraints, external constraints) on the localization solution.

**NEON Location Assistance (NLA) Cloud** holds map information including building models, beacon locations, terrain elevation data, reference pressure and time. An automated map fusion tool



# Figure 5. Distributed Location Service Architecture

processes and fuses crowdsourced map features/signatures (collected during preplanning of a facility or during app use) to develop 3-D navigation maps. Discovered map information is sent to the NLA server where it fuses and stores the map features along with pressure reference, terrain, and other map information. Connection to the NLA server is needed in order to load a priori available map data (including data learned during venue preplanning and reinforced during user use), but once such downloaded data persist; further connection is not necessary. Uniquely, the NEON API allows third party applications and navigation solutions to contribute location constraints.

### **Configuration & Operating Assumptions**

The device library shown in Figure 5 is made up of a navigation engine and sensor hub. The navigation engine runs on an Android while the sensor hub runs on a wearable accessory and optionally both can run on a standard Android device. Figure 6 shows the SWaN service including the associated cloud-based services (location assistance data, routing graphs, map and POI data). The wearable accessory, when used, runs the Sensor Hub software.

<sup>&</sup>lt;sup>8</sup> The sensor hub software delivers infrastructure-free location by modeling user and device motion. If the accessory device (or phone) is mounted by the user (e.g., on a belt), it is possible to get a better estimate of the path the user took. The accessory device also has ultrawideband, which allows improved accuracy. Standard cellular devices already have the sensors required to support the sensor fusion algorithms, but movement of the device (if it is not "worn" on a belt) will increase error in the location solution. Also, standard cellular devices do not make available ultrawideband (UWB) information, which is a high accuracy location input (the latest Apple devices support UWB, but do not provide an interface for application developers).



Source: TRX Systems, June 15, 2018

#### Figure 6: Existing Architecture and SWaN Service

A prototype SWaN application demonstrates the new location and routing capabilities.

The system is not a closed system. Commercial applications will have independent interfaces to their own cloud services (e.g., for notes and personalization), to third party map databases (e.g., to define or access point of interest data), and to other location and routing solutions (e.g., to support metro train location and navigation, for example).

# Chapter 6. Mapping, Location, and Routing Developments

The SWaN deliverable is a navigation and wayfinding mobile service with open APIs for accessible application developers delivering localization, orientation, waypoint navigation, and route guidance. SWaN provides tools for path planning and routing through complex buildings and transportation structures and will support applications that deliver wayfinding for travelers with diverse needs (mobility, vision, hearing, and cognitive disabilities). In this this project, TRX has extended an existing baseline location service (NEON) to support the routing requirements of accessible travelers. Key accomplishments included:

- Location APIs that provide location in complex structures, including overlapping above and underground structures typical of transportation hubs.
- Extension of route mapping tools that allow 3D modeling of routes within complex buildings including
  addition of features (e.g. stairwells, elevators, ramps) and other connecting infrastructure required for
  accessible routing.
- Development of route creation tools that allow definition of feasible routes from any point of interest to any other point of interest with route attributes enabling accessible routing.
- Development and documentation of open APIs that allow determination of a route through a complex structure, between points of interest with support for accessible constraints.
- Implementation of real-time routing constraint algorithms based on intended route through a complex structure
- Development of re-routing algorithms based on actual indoor location in comparison with intended route; implementation of re-routing.
- Implementation of a developer portal supporting application developer use routing APIs (https://docs.trxsystems.com/android-api/routing-api/)
- Support for hackathon users and implementation of feedback from such application developers to enhance environment and routing APIs and documentation.
- Extension of a demonstration user interface and hosting of NEON API Samples (https://github.com/trxsystems).

TRX has developed a routing service with APIs supporting complex transport structures and the tools required by venue owners to model their venue (incorporating building information, defining possible routes and points of interest). A demonstration user interface has been made available to support validation of the underlying functionality and integration documentation and sample applications have been provided to support easy integration with SWaN services.

### Complex and underground transportation structures.

A fundamental requirement of this project is to support navigation within complex transport structures. These structures are often multistory, with complex geometries, high ceilings, and include multiple layers which extend below ground. Interior connections to the metro often exist, complicating entry to these underground structures. The Command Mapper application was extended to support modeling of routes and route determination within these complex transit venues.

Requirement <sup>9</sup>	Functionality Requirement	Implementation and Support <sup>10</sup>
4.2.1.1	The system shall deliver 3D location within complex indoor structures <sup>11</sup> .	Compliant. 3D location is supported within complex indoor structures, including capability to deliver location within structures that have multiple levels within a single floor ("areas").
4.2.1.2	The system shall support preplanning of the venue to deliver higher accuracy location using enhanced mapping techniques.	Compliant. Preplanning is supported to deliver higher accuracy location through enhanced mapping of RF, structural, and other features and metadata.
4.2.1.3	The system shall support location determination, even when entry to underground structures are within a building.	Compliant. Modeling of buildings and navigation is supported where underground entry is through interior structure. Support is provided for such complex such "overlapping" buildings.
4.2.1.4	The system shall support modeling of complex transportation structures such as Union Station in Washington DC.	Compliant. Modeling of complex structures is supported. Union Station within DC has been modeled.
4.2.1.5	The system shall use underground maps to constrain tracking, improving location accuracy.	Compliant. Map shape files are used to constrain location accuracy.

Table 6 <sup>.</sup>	Underlying	Location	Service	Canabilities
	ondenying	Location	001 1100	oupublittes

<sup>9</sup> Numbering in accordance with original system requirements.

<sup>11</sup> Localization is an inherent capability within the NEON service. Note that real-time location and orientation and path traversal and guidance for wheelchair users is only possible with dense UWB (or other) RF infrastructure.

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4.2.1.6	The system shall support both BLE and UWB navigation inputs, with improved accuracy given increased infrastructure (and deliver continued location estimates without infrastructure).	Compliant. BLE and UWB are supported and location with and without beacons has been demonstrated in FHWA Turner Fairbanks building.
4.2.1.7	The system shall support operation with an Android device and a wearable accessory as well as with an Android device alone. To achieve the highest accuracy, use with a wearable device will be required. <sup>12</sup>	Compliant. Higher accuracy with tracking accessory and infrequent UWB beacons was determined to be required for majority of use cases.
4.2.1.8	Intentionally Left Blank.	
4.2.1.9	The system shall provide an error estimate for the location estimate provided. <sup>13</sup>	Compliant. The location API provides an estimate of 2D and 3D error.
4.2.1.10	The system shall provide heading (direction of motion) for the user where a reliable heading can be determined. <sup>14</sup>	Compliant. The location API provides heading.
4.2.1.11	The system shall provide an error estimate for user heading estimate provided. <sup>15</sup>	Compliant. The location API provides an error estimate for user heading.
4.2.1.12	Intentionally left blank.	Intentionally left blank.
4.2.1.13	The system shall support mapping of existing beacons. <sup>16</sup>	Compliant. It is possible to map existing beacons with the NEON Mapper application.

# **Technical Routing Functionality and APIs**

Within the complex transport structures identified above, it is essential to be able to create and follow a route that meets the unique needs of each user group. The table below identifies the objective routing service capabilities for the project and those that have been implemented.

<sup>12</sup> Apple recently announced support for UWB so future iOS may be able to utilize UWB corrections.

<sup>16</sup> Existing Capability

<sup>&</sup>lt;sup>13</sup> Existing Capability

<sup>&</sup>lt;sup>14</sup> Existing Capability

<sup>&</sup>lt;sup>15</sup> Existing Capability

Requirement	Functionality	Implementation and Support
4.2.2.1	The system shall support development of routing graphs for complex transportation venues and other buildings.	Compliant. Development of route graphs is supported within complex venues.
4.2.2.2	The system shall allow a user to start at any point on venue graph and navigate to any other point of interest on venue graph.	Compliant. It is possible to begin at any point of interest, or any lat/long/elevation point, and navigate to any other point of interest by routing the user to the nearest point on the route graph.
4.2.2.3	The system shall be able to create routes based on accessible points of interest.	Compliant. Point of interest-based routes are supported. Any point of interest location can be defined to be a node on the route graph.
4.2.2.4	The system shall be able to add attributes to routes to constrain the routes returned to meet user needs.	Compliant. A route segment has a list of attributes that are associated with it.
4.2.2.5	It shall be possible for the user application to add personal notes to routes. <sup>17</sup>	Compliant; deferred to end user application after discussions with application developers.
4.2.2.6	The system shall support location- sensitive downloading of route data.	Compliant. Map and routing data may be downloaded for the buildings close to where the user is operating. App providers using the API can establish their own policy for downloading (e.g., can request to download an area of buildings through the API). It is possible to download an entire system of connected routes in connected buildings (e.g., metro system).

#### **Table 7: Routing Service Developments**

<sup>17</sup> User defined route notes (notes during the course of travel for use on a subsequent trip) will be able to be stored and provided back to the user through their application, however, will not influence the routes returned. Attributes will influence the routes returned.

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4.2.2.7	The system shall support continued path traversal (real time location determination and distance estimates) on an existing route without a network connection.	Compliant. Routes are downloaded when the user is nearby a building and can continue to be used if a network connection is lost. A network connection is required to obtain the initial route.
4.2.2.8	The system shall support continued guidance on an existing route without a network connection.	Compliant. Routes are downloaded when the user is nearby a building and can continue to be used if a network connection is lost. A network connection is required to obtain the initial route.
4.2.2.9	The system shall support re-routing within a venue (e.g., application requests change in route to nearest exit point of interest, location-based rerouting given user departure from route)	Compliant. Applications can re-route at any time and re-routing is performed when the user is determined to have substantially left the intended course.
4.2.2.10	The system shall support providing routing status such as distance remaining to point of interest.	Compliant. Remaining distance to point of interest is provided over the API in real-time.
4.2.2.11	When entering a building, the system shall download route graph and associated points of interest/notes.	Compliant. Routes are downloaded for buildings nearby and along connecting structural features
4.2.2.12	The system shall support caching of all routes along a path, including emergency routes for a transportation facility.	Compliant, it is possible to cache routes along a path. (Future optimization will be required to optimize this within a metro- wide system).

# Chapter 7. Venue Mapping Application Developments

Venue mapping applications are required to allow venue owners/transit operations personnel to map transit facilities, public buildings, and other structures, and to identify feasible routes through the structures. The Table below defines the Venue Mapping application requirements in support of the location and routing service and identifies those that are supported.

Requirement	Functionality	Implementation and Support
4.2.3.1	The Venue Mapping application shall include a PC-based venue command interface that allow interested parties (DOT, venue operators, and community volunteers) to quickly map a venue (shape of venue, number of floors, floor plans) such as a metro station, airport, mall, etc. <sup>18</sup>	Compliant. Venue mapping tool supports a PC-based command interface to allow venue owners, or other authorized users, to quickly map a venue.
4.2.3.2	The application shall allow definition of Points of Interest within the venue	Compliant. Points of interest can be defined through the Command Application.
4.2.3.3	The system shall add new venue map data defined within the Venue Mapping Application to a shared database of maps. <sup>19</sup>	Compliant. New map data or features can be added to a database by contributors with access to the building editor. End users can also now add passively discovered map data (with lower weight).
4.2.3.4	The application shall allow definition of routing data for the venue.	Compliant.

#### Table 8: Venue Mapping - PC Tool Developments

<sup>18</sup> Existing capability

<sup>19</sup> Existing capability enhanced through complementary R&D investments.

4.2.3.5	The system shall add new (or modified) route data defined by a venue owner within the Venue Mapping Application to a shared database of routes. This shall include support for removing routes that are no longer accessible. <sup>20</sup>	Compliant. Route data can be shared among contributors with access to that venue building model editor. End users can also now add passively discovered map data (with lower weight).
4.2.3.6	The application shall allow definition of route attributes	Compliant. Attributes are automatically populated for features and attributes for route segments can be added through the PC Command Mapping interface.
4.2.3.7	The application shall allow venue owners to place beacons to improve navigation <sup>21</sup>	Compliant.
4.2.3.8	The application shall allow community contributors to provide map and route data. <sup>22</sup>	Compliant. Map data including map data associated with intended and common routes is "relearned" as users operate within buildings. Where there are no feasible routes, and users have not transited a structure, map data is not populated.

The following are the requirements for enhancement of the mobile mapper tool:

#### Table 9: Venue Mapping - Mobile Tool Developments

Requirement	Functionality	Implementation and Support
4.2.3.9	The application shall support preplanning from a mobile device to allow users to map (place beacons, map RF, structural features) from the mobile device	Compliant.

<sup>21</sup> Existing capability.

<sup>22</sup> Existing capability enhanced through complementary R&D investments.

<sup>&</sup>lt;sup>20</sup> Given communications capability, it shall be possible for applications to receive updates to routes during operations. Without communications, any route modification performed by the venue owner will not be accessible by the routing service.

4.2.3.10	The application shall include a validation capability that will to allow venue owners to validate map data and routes in their venues. <sup>23</sup>	Compliant.
4.2.3.11	The app shall allow multiple levels of confidence on supplied/ detected mapping, routing information.	Compliant. Preplanned data contributions are weighted above crowdsourced data.

<sup>&</sup>lt;sup>23</sup> This requirement is an inferred engineering requirement; it is believed something can be developed that could be helpful to venue owners in validating mapped location and routing data that could improve real-time location.

# Chapter 8. Performance Testing and Validation

# Benchmark and Accuracy Evaluation at FHWA Turner-Fairbank Highway Research Center Facilities

#### **Turner Fairbanks Test Scope**

NEON has been extended within the Smart Wayfinding and Navigation Using High Accuracy 3D Location Technology project to support routing within complex public buildings and transport hubs. The NEON solution was installed at the Federal Highway Administration Turner-Fairbank Highway Research Center buildings to support testing and evaluation of the NEON Location Service. The purpose of the test was to get a baseline data set to show the difference in accuracy when using different type of location constraints. The constraints that were tested are: Ultra-Wide Band ranging, BLE ranging, and features.

#### **Turner-Fairbank Test Materials**

- Samsung S7 & Nexus 5
- TRX INU8 UWB trackers
- 6 UWB anchors
- TRX INU8 BLE Tracker
- 9.20 Production software in the FHWA subscription
- 27 Kontakt BLE beacons

#### **Turner-Fairbank Location Accuracy Test Methods**

TRX modeled and mapped the FHWA Turner-Fairbank buildings using the NEON Command Mapper PCbased application that includes the additional route graph creation capability developed in this project. The system was deployed at Turner-Fairbanks to support extended and "random" testing over long term use in a typical work day and also to support measured collection of location and routing accuracy and usability data. Out of the 4 floors in the Turner building, one was equipped with UWB and the rest were equipped with BLE beacons at consistent, but infrequent intervals. The Fairbank building had no beacon infrastructure installed and navigation was supported using the wearable accessory combined with map data collected through preplanning of the facility. Accuracy increases with every position input supplied to the system – even when those position inputs are not provided uniformly throughout the facility (e.g., just at choke points, for example).

The test setup process for the measured testing, which involved two people doing an intentional data collection over the course of a single day, was as follows:

- 1. Pre-map the FHWA Turner-Fairbank buildings using NEON Mapper software.
- 2. Place UWB and BLE beacons throughout the FHWA Turner-Fairbank buildings. Within the Turner building, UWB beacons were placed on only a single floor. BLE Beacons were placed on the other floors. The Fairbanks building had no beacons or infrastructure placed.
- 3. Using NEON Personnel Tracker, start outside to initialize with GPS. Walk the test course checking into preplaced debug markers along the way, and then upload the log to the cloud.
- 4. Use the Reprocessor Tool to remove constraints from the path.
- 5. Use the batch processor to compute location accuracy.
- 6. Use an excel spreadsheet to compute the error metrics.

#### **Turner-Fairbank Location Test Results**

In all tests, location and tracking was initiated outdoors and a solid location was achieved using GPS while traversing the parking lot to the building before entering the building. Results are average 2D error in meters and include improvements to the path from near-real time back propagation, which allows future constraints (e.g., UWB) to support improvement of the overall path. With premapping and occasional BLE/UWB anchor constraints, 95% of the time the location accuracy is within 1.4 - 3.0 meters. The tables show the performance effect of removing different constraints.

Because UWB beacons were installed on only 1 floor, and because it was possible to install BLE beacons in "choke points" where users were likely to walk in close proximity to the beacon, UWB has less of an impact than it might in a very large transport structure. In a large structure with significant open areas, UWB will have a substantially greater impact.

Constraints Applied	GPS, Inertial, Building Footprint Only	GPS, Inertial, Building Footprint + Features	GPS, Inertial, Building Footprint + Features + BLE	GPS, Inertial, Building Footprint + Features + BLE + UWB
User 1, Unit 1 (UWB TU)	6.50 m	2.94 m	1.98 m	1.69 m
User 1, Unit 2 (UWB TU)	7.58 m	4.50 m	2.03 m	1.90 m
User 2, Unit 1 (BLE TU)	8.53 m	4.79 m	3.31 m	3.31 m* no UWB
Sarah 2, Unit 2 (UWB TU)	6.21 m	5.65 m	4.19 m	2.97 m

#### Table 10: Test Result Summary

\*BLE Tracking Accessory cannot receive UWB constraints, so results are BLE only

The following results are represented as a confidence interval 95% for UWB Tracking accessories.

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Test	GPS, Inertial, Building Footprint Only	GPS, Inertial, Building Footprint + Features	GPS, Inertial, Building Footprint + Features + BLE	GPS, Inertial, Building Footprint + Features + BLE + UWB
Total UWB TU	5.9 - 7.6	2.8 - 5.9	1.3 - 4.2	1.4 - 3.0

#### Table 11: Accuracy at 95% Confidence Interval

#### **Turner-Fairbank Route Graph Development and Route Computation**

Routing graphs were developed that connect both the Turner and Fairbank building. Route computation and turn-by-turn directions were validated by routing in between the two buildings. A list of available points-of-interest is presented to the user, and on selection the route is displayed from the user's current location. If turn-by-turn navigation is started, real-time instructions are provided to the user to reach the next intersection of the route graph. Attributes for the route segment can be used to filter the route, such as by avoiding stairs. By dividing points-of-interest into categories, the current location of the user can be used to route to the nearest point-of-interest in that category. For example, the sample application can compute a route to the nearest bathroom, coffee shop, or security desk. Route testing was subjective and as performed by engineering personnel it was determined to effectively support user requirements to reach the intended destination.

#### **Turner-Fairbank Extended Service Testing**

In addition to the intentional test collection, Turner-Fairbank personnel performed continual testing of the NEON service over the course of several months. The objective of this testing was to identify issues that might occur over extended operation, including battery life, possible memory issues, and accuracy issues given random use. Feedback was collected through a process whereby users "submitted logs" to TRX post use of the service for the day. Feedback was also collected automatically in the event of any software errors that triggered an automatic error report. Stability issues were identified and resolved in this long duration testing.

#### **Turner-Fairbank Test Summary**

From an accuracy perspective, the optimal configuration is a stacked configuration of inertial + GPS + Features + BLE + UWB. The use of inertial and mapping technologies dramatically reduces the number of beacons required to achieve good location results and allows these to be achieved even when mobile devices are in pockets or otherwise don't have a clear path to the beacons (not possible with a beacon only technology).

Notwithstanding this, there will be facilities where it is not possible to install beacons, or where it is not desirable to install beacons that must be powered. Therefore, an analysis was performed of the use of features alone and it was demonstrated that features-alone can allow for sufficient accuracy for many

applications. However, to achieve less than 2-3-meter accuracy consistently within large venues, UWB must be used.

A downside is that UWB beacons must be powered continuously. Using a configuration with inertial + GPS + Features + BLE can achieve a similar accuracy, though many more beacons must be placed. The number is still far less than required for a BLE beacon-only location solution and provides good performance when the device is in the user's pocket (unlike a beacon-only solution).

The addition of points-of-interest and a route graph to the building enables turn-by-turn directions in the Turner Fairbanks complex. UWB beacons provide good accuracy which improve the user experience for turn-by-turn navigation in the building.

## Transit Facility Testing – Union Station, Washington D.C.

#### **Transit Facility Test Scope**

The objective of testing in Union Station was to validate the location and routing service and APIs within complex transport hubs. Testing was performed to both identify how the system would perform (accuracy) without infrastructure and whether routing would have utility in a large complex transport facility without infrastructure.

Preplanning of the Union Station Terminal and Metro facilities was performed. No beacons were placed in this facility to minimize disruption to the transit facility and emulate an environment where community contributors "crowdsourced" the map and location assistance data. Only building features, such as inferred structural and RF, are used for location determination. Route graphs were established using available structural point of interest features. Four people executed the tests which were performed in June of 2018.

#### **Transit Facility Test Materials**

- Phone models: Samsung Galaxy S7 and Google Pixel
- TRX INU8 BLE trackers
- 10.0.2 Testing software in an FHWA testing account subscription

#### **Transit Facility Location Accuracy Test Methods**

- 1. Pre-map Union Station buildings using NEON Command Venue Mapper
- 2. Preplan the building using NEON Android Mapper software. Add routes to complex, focusing on the transition between Union Station Transit Hub and Union Station Metro.
- 3. Using NEON Personnel Tracker, start outside to initialize with GPS. Walk and acquire a navigation lock. One tester uses check-ins to align themselves to a test route. Other testers walk the course without check-ins. The "ground-truth" path along the route produced by the first tester is compared to the other paths at each step along the route. These measurements can produce an average 2D error metric from the intended route in the Union Station Transit Hub.
- 4. Use an excel spreadsheet to compute the error metrics.

#### Transit Facility Location and Routing – Building Route Graph Development

The building mapping and preplanning was performed, as illustrated in the figure. This building is complex and demonstrated many of the new features developed – including ability to support routing through multiple areas with different elevation on a single level, and ability to route through connected overlapping buildings (such as the terminal and metro). In the figure below, the pink lines represent available routes through the facility. The green and blue shaded areas show maps of signals that are used as "location assistance" data, complementing the sensors in the user device and helping to improve the estimate of the user location within the facility.



(Green & blue shaded areas show a map of WiFi signals providing location assistance data, Pink lines show available routes through facility)



#### Figure 7: Union Station Terminal Mapping, Route Graphs

(Green & blue shaded areas show a map of WiFi signals providing location assistance data, Pink lines show available routes through facility)

Figure 8: Union Station Terminal Mapping, Route Graphs

#### **Transit Facility Location Results**

In all tests, location and tracking was initiated outdoors. It was possible to acquire a good initialization (location and direction of motion estimate) while outside in front of the transit hub before entering the building. Results are average 2D error in meters and include improvements to the path from near-real time back propagation, which allows future constraints to support improvement of the overall path. In general, the route traced a path from the main entrance of the transit hub onto the platform level of the attached metro station. Note that, since it is difficult to know a precise "ground truth" for a location inside the transit hub due to imprecise floorplans, there is some error inherent in attempting to define accuracy.

The first test looks at average 2D error between ground-truth location and path location with varying levels of environmental data. Since the test was completely infrastructure-free (no beacons of any kind), the only source of constraint (on top of the inertial path) was the building model itself (floor levels and building outline) and feature corrections from mapped Wi-Fi fingerprints and structural features. For each test path, we compute the average 2D error over the four testers for GPS + inertial only (no building or environmental data), GPS, inertial and building model, and GPS, inertial, building model, and mapped Wi-Fi and structural features.

Test Dura		GPS + Inertial +	GPS + Inertial + Building Footprint +
Test Run	GPS + Inertial	Building Footprint	Building Features
Track 1	14.25 m	12.39 m	7.97 m
Track 2	9.33 m	8.07 m	5.63 m
Track 3	29.68 m	16.24 m	11.51 m
Track 4	8.84 m	5.26 m	5.68 m

#### Table 12: Average 2D Error (meters) with Location Assist Data

Building modeling and mapped structural and Wi-Fi features are able to greatly improve accuracy over purely GPS and inertial alone. A 2D Error metric also doesn't account for building and floor level identification, which the system provides and is required for routing in a facility. The system can identify the building and floor and update that information automatically as testers transit the facility, including the indoor transition between the transit hub and the metro platform.

In order to provide a benchmark for the feasibility of routing in a building complex of this size, one tester walked a route as defined by the Union Station complex route graph and provided manual constraints to the system to keep the path aligned with the route, while four other testers walked the same route without providing corrections to the system. By computing average 2D error between the simulated "ground-truth" path and the test paths at every point, the average deviation from a route was calculated.

Tester	Path 1	Path 2	Path 3	Path 4	Path 5
Tester 1	13.74 m	17.44 m	11.15 m	10.70 m	7.89 m
Tester 2	8.86 m	9.48 m	7.18 m	10.08 m	9.84 m
Tester 3	8.70 m	8.86 m	6.56 m	12.17 m	10.86 m
Tester 4	9.00 m	6.89 m	12.62 m	10.95 m	9.92 m
Average	10.07 m	10.41 m	9.40 m	10.98 m	9.62 m

Table 13: Average 2D Deviation (meters) from Route Path through Transit Hub

The results show a fairly consistent result of approximately 10 meters of average deviation from the route for paths in the transit hub. This deviation is significantly higher than the route error given that a group of people were following the same route together, and each person was naturally separated by 1-2 meters from the actual route. This performance was attained without any beacon infrastructure, should improve with time as crowd-sourced features are added to the map (as the service is mapping WiFi and building features in the background), and is on the order of the hallway widths in this building. The addition of beacons, particularly with ultra-wideband technology, at a few key points would improve accuracy as well.



Figure 9: 2D View of One Test Route (Multiple User Paths)



Figure 10: 3D view of Union Station to Metro Transition (Multiple User Paths)



Figure 11: 3D View of Union Station to Metro Platform Transition (Multiple User Paths)

#### **Transit Facility Routing Test/Validation**

Routes from the Union Station main entrance to the metro platform can be computed in our sample Routing App that utilize the connecting structural features between the two building. As an example, routes that avoid stairs and instead use the elevators on the north mezzanine were demonstrated.



Figure 12: Union Station Fastest Route - Includes Stairs



Figure 13: Union Station Accessible Route - Excludes Stairs

#### **Transit Facility Test Summary**

The Union Station transit facility was modeled using building editing improvements developed to handle complex, interconnected routes within structures. Wi-Fi fingerprints and structural features were mapped with NEON mapper. Route graphs and points of interest were then identified for the transit facility. The modeling and feature mapping were able to improve the 2D accuracy throughout the transit facility. The resulting 10-meter deviation from a computed route is a good baseline result for an enormous complex with no installed infrastructure, given data collection by a group such that the actual error would be several meters less.

## Hackathon & Developer User Experience Testing

#### **Hackathon Test Scope**

University of Maryland Baltimore County, TRX's partner on this project, performed a developer/user experience assessment through execution of a hackathon on the UMBC campus. The objective of the hackathon was to verify that the NEON SWaN APIs could support developers creating accessible applications, TRX provided developer support at a hackathon hosted by UMBC and University of California, Irvine (UCI). UMBC and UCI provided an independent review and assessment of the developer experience and feedback.

#### Hackathon Developer/User Experience Test Materials

Materials provided were the TRX NEON application running on commercial cellular devices along with TRX NEON tracking accessories that were paired with the devices using Bluetooth. Each developer received two systems to support development. Starter code developed by UMBC and UCI was provided, which would enable participants to output content, including turn-by-turn navigation instructions, through auditory format. Developers brought and used their own laptops to support development. The TRX developer portal (docs.trxsystems.com) was used to support development as were the sample apps published on Github (https://github.com/trxsystems).

#### Hackathon Developer/User Experience Test Methods

The one-day hackathon was organized as follows:

- 6 participants were recruited for the one-day hackathon, each of whom had one year or more of development experience with the Android OS. 2 sets of participants were paired, and the others participated individually.
- The coding session was divided into two main parts, following an introductory session where the research team described the challenges facing individuals with disabilities when navigating. The TRX team described the development of NEON.
- Participants were given with 1 main task and 2 other supporting tasks. These tasks related to needs of individuals with disabilities when attempting to navigate or orient position within the environment selected. Supporting tasks varied to better evaluate different features within the API.

The participants were provided sample tasks, including:

Task 1: A user with a visual impairment is looking for a seminar hall, so she would like to use the\ voice turn by turn instruction guide to navigate towards her intended destination. She would like information about features and rooms that she passes by on her way to seminar hall.

Task 2: A student with a visual impairment and wants to go to the seminar hall at the other end of the floor, but he does not want to encounter too many people which may impede his journey. He wants to gain an overview of which routes he can take. He can then choose the one which works the best for the situation. Note: the overview does not have to be presented in real time. It should only provide information relating to how to navigate towards the destination.

UMBC checked in with developers during the testing to assess the developer experience:

- Captured critical incidents
- Documented comments on ways to strengthen the API and supporting documentation
  - Captured notes when solutions were presented to TRX
  - Conducted post-hackathon interviews
- Performed supplemental evaluation of API
- Documented hackathon experience

#### Hackathon Building Modeling, Route Graph Development

Prior to the testing, TRX personnel modeled the UMBC Human-Centered Computing (HCI) building and established route graphs throughout the building using the PC-based NEON Command Mapper software, including the route graph creation capability developed in this project. HCI is housed in the Department of Information Systems, at 1000 Hilltop Rd, Baltimore, MD 21250.



(Red Lines: Available Route Graphs Through Building)

#### Figure 14: UMBC Hackathon Preparation - Building Modeling, Route Graphs

#### **Hackathon Test Results**

Participants reported that it was easy to understand the structure of the code/functionality offered; in particular, it was easy to understand the update() function, calling functions, and the information being passed.

Developers reported that the API methods were well defined and easy to handle, and that the structure of the API supported flexible implementation approaches. Different groups could and did implement the same tasks using different methods. The code was found to be easy to modify; the framework was easy to use and modify according to the user needs. The flow of code was also thought to be well presented and functions were well defined.

Some of the developers experienced difficulty in reading through Javadocs in timeframe of the hackathon. Challenges included: a) finding appropriate methods (adding a search option or giving them some keywords for reference would help), b) navigating through classes and understanding the hierarchy of classes, and c) issues with finding the correct method to use for a function. The documentation was written in a way that required that developers go through all content to effectively develop.

Enhancements were made to the API documentation based on UMBC and developer feedback and the TRX team's observations of developers using the APIs. Modifications were focused on usability of the documentation

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and consisted of adding an overview of the system architecture and API to the documentation home page and a search function for the developer documentation on the developer portal.

The process of preparing for the hackathon raised issues relative to ease of use of the PC-based route creation capability; usability of this application was enhanced as a result of the hackathon preparation.

Finally, roadmap items were defined as a result of the hackathon experience including: a) the separation of proximity information from within route updates (such that one could access feature proximity – e.g., how close the nearest restroom is – separate from routing updates) and b) the desirability of the addition of a building details capability in the environment API (such that it would be possible to query for building information as a function in itself).

#### **Hackathon Test Summary Recommendations**

One of the most important benefits of the hackathon was that it provided a high maturity target for development – outside developers who would be using the APIs to develop their own applications. This benefit can't be overstated; it drove the development maturity target and resulted in significantly more testing and maturation work prior to the hackathon than would have otherwise been planned. The hackathon also resulted in testing of the written documentation in a stressful situation – and made it clear that providing additional context for developers right up front and providing additional navigation and search mechanisms would be beneficial.

The insight into requirements outside of real-time routing was also of interest. Proximity information and the desire for building and structure orientation in real-time was valued part from real-time routing, and providing such information – with a path planning app – could be a potential easier starting point for a transit agency application. Clearly, a number of organizations are uniting proximity information with commercial points of interest outdoors – but uniting it on a location-based service with structural and transit points of interest indoors is something not yet available.

### **Final Transit Facility Testing**

#### **Final Test Scope**

To verify that SWaN is able to provide users with accurate en-route assistance, TRX performed tests by riding roundtrip the Washington D.C. metro from Greenbelt Station to Fort Totten. In these tests, individual testers used TRX's commercial NEON® Personnel Tracker application with Routing enabled (i.e., leveraging the SWaN service) to generate routing directions, which were followed by testers to reach their destinations. The success of the SWaN application was based on the tester's ability to follow the generated directions easily and arrive at the intended destinations.

#### **Final Test Materials**

For these tests, four different testers participated with their own set of equipment. The following devices and applications were used to perform SWaN testing and all necessary preparations:

- Android Smart Phones Nexus 6p, Google Pixel, Google Pixel 2, Samsung S7
- NEON® UWB Tracking Units (4)

- NEON® Personnel Tracker with Routing enabled<sup>24</sup> (i.e., leveraging SWaN routing service APIs)
- NEON® Command Mapper

#### **Final Test Methods**

The tests were performed in two stages: (1) preparation; and (2) testing. The purpose of the preparation was to ensure that sufficient digital infrastructure is available for accurate tracking. This infrastructure, including building models and route graphs, provides essential components to the SWaN system for reliable and accurate location.

To test multiple conditions, two scenarios were tested: (1) routing from Greenbelt to Fort Totten; and (2) routing from Fort Totten to Greenbelt. These scenarios tested both starting and ending at the end of a metro line as well as scenarios where the trains both started and ended transit underground. Unlike other metro stations, stations at the end of a line allow trains to arrive on either side of the platform. Beginning a metro ride underground removes the use of GPS to assist with onboarding and routing at the beginning of the train segment.

- 1. The tester started in the parking lot at the metro station. Tester's location was initialized with GPS as they walked through the parking lot.
- 2. The tester walked through the station entrance. Once a tester was located inside the station, SWaN provided a notification that routes are available.
- 3. The tester then followed the prompt and selected a routing destination at the entrance of the other metro station. After a few moments, SWaN would begin routing and display the first direction.
- 4. The tester then followed the directions provided on the screen until reaching the destination.

A limitation of this test was that no beacons were used – the testing was performed entirely without infrastructure. Location improvements, such as beacons, could easily be added to the station infrastructure at the discretion of the transit agency; this capability is already supported.

#### Final Test Building Modeling, Route Graph Development

Using the Command Mapper application, building models were created for metro stations including structural features. These stations included Greenbelt, College Park, Prince George's Plaza, West Hyattsville, and Fort Totten.

<sup>24</sup> The TRX Personnel Tracker application was used as the application to test the SWaN Service



Figure 15: Fort Totten Building Model Including Metro Line and Route Graph

#### **Final Test Results**

The goal of these tests was for testers to be able to route roundtrip from Greenbelt to Fort Totten. The tests were successful if the instructions provided were sufficiently accurate for testers to follow closely and reach their destination. Testers' subjective feedback was given on how easy it was to understand the automated directions, the user interface, and the overall experience.

Testers were able to successfully route between both metro stations from Greenbelt to Ft Totten, and then from Ft Totten to Greenbelt. Testers report that directions were generally accurate and easy to follow:

Testers report that directions were generally accurate and easy to follow.

- Testers were able to route from the entrance of one station to the entrance of the other by simply following the automated directions.
- The automated directions were very clear and easy to follow. Most directions told the user where they were and where to go next. If the user was on a platform waiting for a train, accurate information was provided about the schedule.
- The arrow indicating which direction to walk was very useful and made it clear which way to go in open areas.
- The information about arriving trains was very accurate and made it very easy to get on and off the trains.

Desired future enhancements identified by testers and developers included the following:

- Define a minimum amount of time to display a direction. This may prevent directions from being rushed in some areas like turnstiles. (Application developer function)
- Add the ability to define an area as an entrance to a region. This may make routing easier as well as more accurate. (Future possible mapping enhancement).
- Add the ability to define whether an escalator is going up and down. (Future possible mapping enhancement).
- Include a special case for the side of the platform a train is located on at the end of the line. (Future possible routing enhancement and possibly supported through transit API development).
- Support integration with end-to-end navigation to allow routing to the specific exit nearest the end-to-end route. This requires that the application select the appropriate exit from the available exists based on the next step in the end-to-end route. (Application developer function).

#### **Final Test Summary**

Many tools and features have been developed for SWaN in the NEON system. The success of these metro station tests has demonstrated that users are able to utilize the SWaN tools to navigate public transportation in Washington, D.C. Navigation was clear and easy to follow while only requiring a destination input from the user. Testers were able to route through metro stations with ease, and functionality enhancements were identified that can influence future development. Areas of enhancement for application developers, for the routing service itself, and for transit station APIs were identified.

# **Chapter 9. Testing Lessons Learned**

Testing in Turner-Fairbank and Union Station clearly demonstrated that the core location and routing service could work without infrastructure, however, to achieve the highest accuracy results (e.g., to support turn by turn routing), addition of beacons (BLE or UWB) at "choke points" or select areas within the facility is desirable. The scale of transit facilities illustrated the weakness of modeling paths as single lines, or "roads," in the way a typical vehicle-based navigation system function. For example, the large central hall of Union Station cannot easily be modeled as a series of routing lines. In subsequent development, zones were created which allowed establishment of a user route through such open spaces were implemented.

The Hackathon had a significant impact on the project and the maturity of the API development. Documentation had to be thorough and was tested in preparation for the hackathon. The documentation was also updated after the hackathon. The inclusion of proximity information within route updates was reassessed based on hacker feedback; it became clear that these two functions would benefit from separation. Additional roadmap items from an API development standpoint (specifically building features and detail) were also defined based on hacker feedback. The building route definition and real-time routing function was tested, issues were identified, and usability was improved.

Final testing within the Washington metro allowed demonstration and enhancement of end-to-end routing through complex transit hubs including end to end routing over train segments. By integrating an end-user application with metro and SWaN APIs, it was possible to complete the routing function from entrance to the metro station, through the train segments to a second metro station, and exiting the second metro station. This functionality was validated both with trains starting underground and with trains starting above ground. Lessons learned included the fact that:

- Terminal station routing may vary among different subway/metro environments, and even within the same transit agency, different times of days, or even in subsequent transit rides at approximately the same time of day. In some architectures, trains may always end and start at the same side of the track. In others, they may switch tracks even within the same stop (sometimes transiting one side or the other of the track). This is more typical at the end of a line.
- Transit agency metro/subway APIs are required as complementary input to enable end to end routing and they are specific to the transit agency and vary between cities (e.g., APIs for the Boston subway are different from those in DC). APIs are evolving and with additional capability will be able to signal more to the application developer, including (for WMATA) which real time train position (segment) is associated with a particular oncoming train arrival (i.e., which train ID is arriving). This is a particularly useful piece of information for routing.
- Caching of map information (to enable access to the entire metro even if internet access is not available in some sections) requires some optimization. This development is best performed in a subsequent effort focused on complete transit system deployment. At the beginning of a route, the data can all be downloaded for the complete intended route. The primary challenge is in dealing with route changes and emergency routing. If only route data for the intended route is downloaded, internet access is required to access route changes.

Prior to this development, it was clear that the optimal performance would be attained with the installation of infrequent beacons at particular areas along the route to allow for the best localization accuracy in big structures where decisions need to be made with respect to routing (or where a location-dependent user function, such as purchasing a ticket, or transiting a turnstile, must be performed).

# Chapter 10. Developer Portal and Developer Tools

A developer portal has been launched to allow developers to access the NEON APIs for location and routing and to support the application and documentation access required to develop location and routing applications for transit venues (docs.trxsystems.com):



#### Figure 16: Developer Documentation at docs.trxsystems.com

Because a venue must be mapped, it is initially intended that portal (and associated APIs and tools) will be made available to transportation venues with an interest in accessible navigation (and overall user navigation) application development. This will allow the transit authority to support mapping of the building and ensure the tools (navigation and route maps) are available prior to application developer use.

The developer portal is intended for use by experienced application developers such that Android developers can quickly and easily use the system for a mapped venue. Portal tools are accessed through support.trxsystems.com and include a new NEON Docs portal that provides extended developer support.

Portal Tools include:

- API & documentation
- Sample applications

#### • Access to location service APK<sup>25</sup>

The following is a brief summary of the underlying tools used to make the developer portal:

#### Jekyll (https://jekyllrb.com/)

Jekyll is a configurable static website generator. Most of the documentation is written in Markdown (<u>https://en.wikipedia.org/wiki/Markdown</u>); Jekyll takes those files along with some configuration files to produce a full website. GitHub Pages, which is often used for code documentation is also based on Jekyll (https://help.github.com/articles/about-github-pages-and-jekyll/).

#### Doxygen (http://www.stack.nl/~dimitri/doxygen/)

Doxygen is a tool that allows annotations directly inside of the code to produce a static website. Every function call and class can be annotated with Javadoc comments and Doxygen automatically parses those comments to generate the documentation. Doxygen is used to produce documentation for the API part of the codebase.

#### Bintray

Customers will access the API via a compiled binary instead of adding the source code directly. Bintray (<u>https://bintray.com/</u>) is used to host a Maven (https://maven.apache.org/) repository that contains the compiled API library. This approach is detailed in the documentation so that customers can use the API.

#### GitHub

Customers will access Sample applications including source code via GitHub (<u>https://github.com/trxsystems</u>).

<sup>25</sup> Developers must have a license key to access the location and routing service APKs.

# Chapter 11. Program Summary and Takeaways

During this program, TRX developed a Smart Wayfinding and Navigation service that delivers path planning and routing capabilities for application developers. The focus of the program was to provide tools required by venue owners to allow them to establish route graphs and by application developers to allow them to establish a range of independent travel applications. Complemented by an existing mobile location and mapping service – the TRX NEON service - these tools:

- Support development of applications that deliver navigation, mapping, and routing services for users with specific accessibility needs.
- Map complex transit hubs including development of 3D model of routes through the structures. Mapping is performed by venue owners who also establish route graphs and add navigation information (WiFi, BLE/UWB beacons).
- Support identification of points of interest within complex transit hubs that may be useful to path planning and real-time routing. Venue owners can define points of interest which are made available through the routing APIs.
- Provide mobile APIs that deliver real-time location within complex transit hubs, including location within 3D.
- Provide mobile APIs and sample apps that deliver en-route assistance and situational awareness for users as they transit through complex structures.

As part of the overall SWaN capability set, PC-based route creation tools were developed to allow transit venue managers and operators to create and add route graphs and accessibility information to facility maps. These maps and routing graphs are then made available to application developers through mobile application developer interfaces (APIs).

User need evaluation and developer testing provided a number of interesting insights into possible SWaN service enhancement and priorities for future developers of accessible travel applications:

- <u>Facility Overview/Orientation</u>: Basic route planning and facility "orientation" is a valued function and may
  initially provide significant value to the user with modest investment. I.e., Developers felt that users would
  value having an overall orientation and insight into features within the building as they enter the building,
  such as the entrance at which they are currently located, the location and number of elevators available,
  location of nearest rest room, and general route overview from their point of entrance to point of destination.
  This would be a straightforward capability for an application developer and would benefit from some
  incremental additions to existing APIs.
- <u>Need to Provide Exit for Destination as part of "Complete Trip"</u>: Delivering insight into the correct exit for the ultimate intended destination would also be valuable as it is easy to exit a facility and not be close to the intended destination. For those with accessibility issues, this "longer route" can be an issue. This is a complete trip challenge that is solved through integration with outdoor navigation systems which would allow selection of the best exit as part of a Complete Trip.
- <u>Infrequent Infrastructure at Decision Points:</u> Real-time routing is immensely helpful, but less so if the route is not sufficiently accurate. Selective installation of infrastructure is required at points where decisions must be made, where location-based user actions must be taken (purchasing a ticket), etc. Select infrastructure

would also accelerate determination of location when starting indoors (as it can take time to get sufficient precision using mapping alone). However, sensor-based systems and map data (structural features and WiFi) do significantly minimize the infrastructure requirements such that infrastructure (beacons) can be deployed only at such decision-oriented locations and not throughout the structure. Planned route is also be used to improve localization results and minimize infrastructure requirements.

• <u>Infrequent infrastructure would also be beneficial at the platforms where the train stops to better predict</u> which side of the terminal station was used for final train stop. This technique could be used to get around the lack of APIs from transit agencies that provide this data, or could complement them to provide more precision.

One clear element of the overall program assumptions that were validated based on the user needs assessment, developer hackathons and associated feedback, and TRX developer testing is that transit station partnerships are required to effectively deploy assistive routing. The transit station must develop and maintain the map accessibility information, including providing the map information, maintaining map information (to reliably support "re-routing" when major routes are unavailable versus waiting for user identification after the fact), and needs to provide the APIs required to associate trains to train segments. These are all reasonable functions; however, georeferenced map data and accessible point of interest data is not currently available through transit station APIs. The NEON and SWaN services provide a mechanism to hold digitized, georeferenced maps and could support delivery of such functions.

The SWaN program delivered a significant element of the end-to-end trip – navigation and accessible routing within complex transit hubs. However, there are many more elements required to support fully accessible independent travel for users of all abilities. A beneficial next step would be to implement a prototype in a key metro area – supporting accessible navigation from user residence over relevant transit nodes and through a key transit hub. Development of this type of a prototype complete trip application would prove out the utility of the technology supporting each of the trip segments, mature the underlying accessible navigation, routing, and API technologies through actual deployment and use, and connect each sement with a top level application supporting the end to end planning and navigation functions required.

# **Chapter 12. Document Revision History**

#### **Table 14: Document Revision History**

Version Number	Description of Change(s)	Created/
0.1	Draft	TRX
1.0	Final Draft	TRX
2.0	Final based on comments provided by program team, internal review.	TRX
3.0	Draft of final report.	TRX
3.1	Second draft of final report.	TRX

# Appendix A. Tracking Accessory Specifications

NEON Tracking Un The NEON Tracking Unit is a w of sensor data to deliver 3D ir	it Specification
	idoor location.
Part Number	NEON-TU8B: Bluetooth Tracking Unit NEON-TU8U: Ultra-Wideband Tracking Unit NEON-TU8B: Bluetooth Tracking Unit with Belt Clip
General Properties	
Size	2.1 x 2.6 x 0.75" (without belt clip)
Weight	52 x 66 x 19mm
weigin	58 grams
Power	660 mAh internal rechargeable battery
Changing	Operational use 6-12 hours dependent upon application settings
Charging	Micro USB 500mA max charge current
Temperature	Operating   -20°C to 60°C
	Charging   0°C to 45°C
	Storage   -20°C to 45°C <1 month, 65 ± 20% relative humidity, non- condensing
Battery Safety	UL1642 approved cells
	Overcharge protection
	Overalischarge protection
Enclosure	Lexan Resin 121R
	Silicone Perimeter Gasket
	Designed to IP67
	Designed to UL 94V-1 Designed to UL 2054
Belt Clip	Zytel 101L NC0103
Sensors	
Dead Reckoning and	3 Axis Gyroscope
Context	3 Axis Magnetometer
	Barometric Pressure Sensor
Ranging	BLE RSSI, Compatible with iBeacon, Eddystone, and TRX beacon
Environmentel	UWB lime of Flight <sup>2</sup>
Certification	FCC Part 15: CE: IC1: KCC1
Applies only to Bluetooth device Applies only to Ultra-Wideband device	
Applies only to Belt Clip	
TRX Systems, Inc.	Website: www.trysystems.com
TRX Systems, Inc. 7500 Greenway Center Drive. S	Website: www.trxsystems.co uite 420 Email: info@trxsystems.co

Source: TRX Systems, June 15, 2018

#### Figure 17: Tracking Accessory Specifications

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