Accessible Transportation Technologies Research Initiative (ATTRI) Impact Assessment White Paper

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16. Abstract

The Accessible Transportation Technologies Research Initiative (ATTRI) is an accessibility-oriented research project supported by multiple partners including: the U.S. Department of Transportation (USDOT); the Federal Highway Administration (FHWA); Federal Transit Administration (FTA); Intelligent Transportation Systems Joint Program Office (ITS JPO); and the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR). The goal of ATTRI is to use innovative applications to increase the accessibility of transportation for people with disabilities. This is Task 4, the Impact Assessment White Paper. This white paper provides an overview of industry developments regarding technologies to improve mobility for people with disabilities. This white paper also introduces evaluation metrics that researchers can use to assess projects that implement these technologies.

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Introduction

This white paper provides an overview of industry developments in the topic area of mobility technologies for people with disabilities. This white paper provides updates on four key areas of interest: 1) smart wayfinding and navigation systems, 2) pre-trip concierge and virtualization, 3) robotics and automation, and 4) safe intersection crossing. It also identifies potential evaluation metrics for projects that implement these mobility technologies. The research team classifies these metrics as they would apply to different socio-economic scales. For each evaluation metric, the research team provides a definition; units of measure; the desired directionality (e.g., whether an increase, decrease, or no change in the metric is a desired outcome); and potential data sources. This paper also identifies the project scale at which these metrics can be applied (i.e., prototype, regional, or national level). Finally, this paper demonstrates how to apply the evaluation metrics using data provided from a U.S. Department of Transportation (USDOT) Accessible Transportation Technologies Research Initiative (ATTRI) application project.

Background

ATTRI is a USDOT initiative to develop and implement applications to improve mobility options for travelers, particularly those with disabilities. The ATTRI program aims to remove barriers to transportation for people with visual, hearing, cognitive, and mobility disabilities. The ATTRI program's three user groups of interest include: 1) people with disabilities; 2) veterans with disabilities; and 3) older adults. ATTRI focuses its vision on the complete trip, which considers accessibility for travelers from origin to destination. For a trip to be considered complete, travelers must be able to travel from their origin to destination without a single segment (or link) of their travel chain being inaccessible.

The ATTRI Complete Trip Vision

ATTRI is investigating different technologies and strategies that can be integrated to allow older adults and people with disabilities to seamlessly and independently plan a complete trip and then experience independent, comprehensive, safe, and reliable travel to work sites, educational programs, health facilities, and social and recreational activities.

Under ATTRI, the USDOT has identified four application areas of interest:

1. **Smart Wayfinding and Navigation Systems:** Helps travelers, particularly those with disabilities, safely and independently reach their destinations by providing real-time information, localization, and situation awareness to assist in navigating indoor and outdoor environments, including path planning and detouring around blocked routes or hazards.

2. **Pre-Trip Concierge and Virtualization:** Provides pre-trip planning and en-route traveler information to travelers with disabilities, their family members, and caregivers. Applications under this area offer users a virtual environment to familiarize themselves with their travel before the trip and the ability to pair transportation services based on user needs.

3. **Robotics and Automation:** Provides personal and independent mobility options across the entire travel chain. Applications under this area can bring transformational changes to independent living and overarching transportation barriers for people with disabilities using collaborative robots that provide concierge and assistive services to individuals at different stages of their travel chain.

4. **Safe Intersection Crossing:** Enables pedestrians to use their connected mobile devices to interface with vehicles, traffic signals, and other infrastructure to receive context-based information related to pedestrian and built environments that helps them cross an intersection safely. Applications under this area use guidance notification and alerts in accessible communication formats to optimize the users' travel experience.

The following subsections of the introduction provide: 1) an overview of recent developments and market trends for applications that aim to improve mobility options for travelers with disabilities; and 2) a summary of current ATTRI applications. Following the introduction, this white paper identifies a list of potential impact metrics that researchers can use to evaluate ATTRI applications and similar technologies. The paper summarizes these metrics and describes them in more detail. The purpose of the white paper is to serve as a guide for individuals planning evaluations of ATTRI projects at the prototype, regional, or national levels.

State of the Industry

The development of applications to improve mobility for travelers, particularly those with disabilities, is a growing industry. Mobility for people with disabilities has increasingly received attention from multi-industry stakeholders as several trends converge including: 1) an aging population, 2) the growth of digital technologies, and 3) a focus on social equity and inclusion.

Industry stakeholders are approaching efforts to increase accessibility from different perspectives. Some applications focus on changing standards for digital products to meet accessibility requirements, while others are making digital products designed to increase accessibility. Still others are focused on more traditional assistive devices (i.e., "smart" canes). The following sections detail recent industry developments categorized by the four ATTRI application areas.

Smart Wayfinding and Navigation

Cities often lack infrastructure that supports safe, easy, and assured travel for individuals with visual or physical disabilities. To travel only a few blocks, individuals with disabilities may need to memorize complex bus routes and timing, have a working knowledge of city streets, and/or navigate through unfamiliar intersections. Several cities and companies, however, have started projects to improve transportation accessibility, primarily for visually impaired citizens with personal smartphones. Notable projects tend to fall into two categories:

- Increasing accessibility through frequent real-time navigation updates
- Using smartphones to decipher various travel and obstacle information from the environment.

Navigation apps intended for users with disabilities include BlindSquare and ClickAndGo, both of which aim to offer frequent real-time navigation updates for individuals with visual impairments. For example, BlindSquare, a $40 app released in May 2012, uses the global positioning system (GPS) to pinpoint a user's location. The app then queries (i.e., requests and retrieves matching information) the search-and-discovery mobile app, FourSquare, as well as the open source map data project, OpenStreetMaps, for information about the surrounding environment. During the trip, BlindSquare provides continuous audio updates on the trip including:

- Bus and metro stop schedules and status (arriving/departing)
- Distance to intersections
- Information about the surrounding environment, such as the presence of businesses, walking paths, and curbs (BlindSquare, n.d.).

The ClickAndGo Wayfinding App is another navigation app, but it focuses on providing indoor navigation support. ClickAndGo relies on a system of iBeacons, Bluetooth receivers that use a phone's Bluetooth signal to determine a user's relative distance and location within a venue. Once the user is within the network of iBeacons, the app provides step-by-step directions to enter, exit, and navigate a venue with constant orientation guidance (Duggan, 2014). In 2018, ClickAndGo installed its iBeacon system at Swarthmore College and the University of Alaska-Anchorage (News and Press, n.d.). BlindSquare also supports iBeacon information, which, where installed, extends the range of its navigation support from outdoors to indoors. BlindSquare pairs with third-party navigation apps, such as Google Maps, to provide points of interest and navigation. In contrast, ClickAndGo Navigation custom-compiles its data through mobility specialists. Due to this, BlindSquare is more readily available but may not provide as detailed and accurate information as ClickAndGo.

Several major companies are working to improve travel accessibility through constant navigation. Google recently updated their navigation system (Google Maps) by adding a "Detailed Voice Guidance" feature that, much like BlindSquare, provides information regarding:

- Upcoming intersections
- Distance until a change of direction
- Confirmation of rerouting if the user goes off-route (Sugiyama, 2019).

Moovit, a public transit navigation smartphone app, uses GPS location data from a user's phone along with real-time public transit data (when available) to alert users when to get on and off public transit based on their destination. Moovit also orients users once they have deboarded based on their phone's orientation (Kim, 2019).

In addition to industry efforts to provide continuous navigation updates, several projects aim to increase accessibility by using a smartphone's camera to capture information about the surrounding environment. One key example is NaviLens, a company with a system of bright and colorful QR-like codes that contain venue information (Swain, 2019). A smartphone can read NaviLens' system of "bi-dimensional" codes from long distances. Unlike a QR code, a smartphone does not need to focus on these bi-dimensional codes and can easily read the codes while rotating and moving. These codes typically map out a venue—noting the locations of features like elevators, vending machines, and restrooms, among others. The codes also provide transit information, such as public transit arrival and departure times. The company's technology has been used in Barcelona since early 2019, where it debuted as a pilot program in one subway station. The city government has since expanded the system to nearly all public transit areas, including bus stations, metro stations, and public transit signs. NaviLens demonstrated its technology through a pilot in New York City at the Jay St-MetroTech Station in Downtown Brooklyn from October 2019 to December 31, 2019 (MTA Headquarters, 2019).

Pre-Trip Concierge and Visualization

People with disabilities often attempt to overcome the challenges that come with navigating new areas through extensive planning. However, the lack of accessibility-related information (i.e., bathroom size, ramp availability, or support for visual impairments) and other support online limits planning. Most technologies in this topic area attempt to reduce gaps in planning capabilities by improving the availability of accessibility-related data and increasing accessibility services in the planning stage.

An abundance of crowd-sourcing projects and apps provide accessibility-related data in a trip-planning form, such as AXS Maps, the University of Pennsylvania's (UPenn's) Accessibility Mapping Project, Access Now, and Google. AXS Maps and Access Now both offer rating systems where users can rate locations and business based on how accessible the site is, from one star (not accessible) to five stars (easily accessible) (AXS Map, n.d.) (Access Now, n.d.). UPenn's Accessibility Mapping Project, which documents accessibility for buildings on the UPenn campus, allows a user to retrieve information in the form of text, audio, or video (Berger, 2018). Google and Yelp crowdsource accessibility data through users and add it to their existing business information (Blair-Goldensohn, 2018) (Rowe, 2019).

Due to the relatively novel nature of accessibility-focused crowdsourcing projects (an early crowd-sourced accessibility map, Wheelmap.org, was developed in 2010, and AXS Maps followed in 2012) and competition with other mapping services, many crowd-sourced maps that focus on accessibility are not comprehensive. Google Maps provides a large quantity of data on its platform, with details for over 40 million companies added in the year between the launch of its accessibility campaign in 2017 to October 2018 (Blair-Goldensohn, 2018). However, due to the challenges of mapping and providing accessibility information, Google's information may be misrepresented by data provided by people who do not understand the complexity of documenting accessibility features. Conversely, AXS Maps and Access Now have detailed instructions for uploading data, demonstrating a tradeoff between quantity and quality from big companies like Google and specialty maps like AXS Maps or Access Now.

Major transportation and trip-planning services are introducing accessibility-related services. In 2018, Google introduced a wheelchair-accessible routing preference, allowing users in major cities to search for the fastest wheelchair-accessible route (D'Onfro, 2018). Lyft and Uber have added new partnerships and services to increase wheelchair-accessible vans and services, such as Lyft's FirstTransit and Uber's UberWAV (Saddiqui, 2018) (Lyft, 2019).

Robotics and Automation

In comparison with the previous topic areas, robotic and automated technologies designed to enhance mobility for people with disabilities are primarily in the research and development phase. Most of the technologies under this area are designed for wheelchair users. A few of the technologies that are available include:

- **Microsoft Seeing Artificial Intelligence (AI)** is a free iOS app released in 2017 that uses AI and a smartphone camera to describe the world for individuals with visual impairments. Its AI can recognize text, people, objects, and scenes; the latter can provide assistance in navigating their surroundings. In December 2019, Microsoft expanded Seeing AI to five additional languages (other than English): Dutch, French, German, Japanese, and Spanish (Microsoft, 2019).

- **Google Lookout** is a free Android app that uses AI and machine learning to pictorially identify objects through a smartphone camera. The app was released in March 2019 and is currently available on Android 5 and above devices. Similar to Seeing AI, Lookout is meant to provide people with visual impairments with information about their surroundings. The two apps have similar features and functionality, with the main distinction being that they use different operating systems, and Seeing AI has been on the market for a longer period of time (Vincent, 2019; Google, 2019).
- **KINOVA JACO Assistive robot** is a robotic arm meant to assist individuals with limited or no upper limb mobility. The product was launched in the United States in 2009. The robotic arm, which allows for 16 movements that mimic the functionality of a human arm, can be mounted on a wheelchair and uses the same power source as the wheelchair. The robotic arm can assist those with mobility disabilities with everyday travel tasks, such as paying for tickets or pushing crosswalk buttons (Kinova, n.d.).

Many projects aim to build “smart” wheelchairs that provide a higher level of autonomy than traditional wheelchairs. Intel and Hoobox Robotics partnered to create the Wheelie 7, a toolkit that allows a wheelchair to be controlled through facial expressions. The wheelchair toolkit is meant to increase independence and mobility for wheelchair users, particularly those with quadriplegia and motor neuron disease, by providing high-precision immediate response. The beta version was released at the Consumer Electronics Show 2019, and Hoobox is currently accepting applications for its waiting list as it prepares for large-scale manufacturing (Hoobox, n.d.). ADAPT technologies is developing a wheelchair that may upload obstacle data to the cloud, navigate through crowded areas autonomously, and intelligently map its surroundings (Stewart, 2019). Imperial London College received a $50,000 grant to continue to develop an artificially intelligent, eye-controlled wheelchair (Malewar, 2018).

Toyota Industries has developed a small robot that performs basic tasks like carrying bags or fetching objects, which will be on display at the Tokyo 2020 Olympic Games to usher people with mobility impairments to their seats and deliver drinks and food (Tarrant, 2019). Toyota also sponsors the Mobility Unlimited Challenge, which awards four million dollars in funding to projects that increase autonomy for people with lower limb disabilities. The most recent winners include two supportive exoskeleton designs, a smart wheelchair, a vehicle sharing platform, and a supportive calf sleeve that stimulates leg muscles to aid walking (Haque, 2019).

Safe Intersections

In contrast to the previous topic areas, there are few projects that focus on enabling safe intersection crossing for people with disabilities or people with limited mobility. Those that exist are mainly focused on increasing visibility and access to intersection lights. In October 2019, Stratford City in Canada launched a pilot program called “Key2Access,” a receiver-based crosswalk system that allows individuals with mobility or visual impairments to use a mobile app or key fob to activate a crosswalk signal without having to reach for a button (Simmons, 2019). In May 2016, the Illinois Department of Transportation outlined stoplights with yellow reflective tape to increase visibility at night for drivers (Erickson, 2016).

There are mobility technologies that are not intersection-focused, although they do have intersection safety applications. Wayfinding apps like BlindSquare or Google Maps alert users when they are approaching an intersection. Mobile apps, such as Microsoft Seeing AI and Google Lookout, may also help to identify crosswalk signs for individuals with visual impairments.

Developments within the industry are likely to continue to exhibit increasing crossover in applications. That is, applications designed for one use case or situation may need to be able to handle other situations to be of practical use. For example, developing new technologies that more broadly address wayfinding and pedestrian navigation can help improve the safety of intersections . Other technologies will similarly overlap and inevitably need to address the use case of crossing intersections. The crossover of benefits across technologies may be similar to the crossover in benefits that are achieved through the principles of universal design, where adherence to one principle can generate improvements and benefits across multiple use cases and applications.

ATTRI Applications

Based on the four application areas identified for the ATTRI program, the USDOT awarded application development funding to several teams to develop technologies that enhance travel accessibility for individuals with disabilities. Table 1 summarizes funding that USDOT awarded for a total of seven applications. These technologies are currently under development. The evaluation metrics described in the following section are intended to guide future evaluations of these applications and similar technologies.

Table 1. ATTRI Applications

Application ***ATTRI Team***	**Description**
Wayfinding and Navigation	
Smart Cane for Assistive Navigation (SCAN) *City College of New York*	SCAN is a smart-cane hardware that integrates new algorithms into the Intelligent Situation Awareness Navigation Aid (ISANA) system, a wearable technology that interprets the visual environment in real time. The application aims to mitigate the problems caused by an imperfect user interface, tackle technical challenges in complex indoor environments, and expand the ISANA capabilities to provide blind users with independent travel in transportation terminals and outdoor pedestrian environments. When the navigation mode is enabled, the software will guide a robotic cane that uses a motorized ball at the tip to provide navigation guidance to the user.
SMART Wayfinding Specification *AbleLink Smart Living Technologies*	SMART Wayfinding Specification is a common wayfinding media standard, or route format, for presenting travel instructions to individuals with cognitive disabilities. This will allow wayfinding technology users to access and share routes that enable them to use public transit more independently. The project also aims to develop a cloud-based library of standardized routes that adheres to the Specialized Media for Assisting Route Travel (SMART) standard for use or customization by any user of the application. The route library and standard will be integrated into AbleLink's WayFinder mobile application.

Application ***ATTRI Team***	Description
AccessPath *Pathways Accessibility Strategies*	AccessPath is a pedestrian wayfinding tool tailored toward wheelchair users and individuals with visual impairments. This project includes wayfinding algorithms using a connected network of sidewalks, pathways, and crosswalks that integrate pathway quality. The tool provides a user interface tailored toward wheelchair users and people with visual impairments, and it can be customized based on a user's preferences.
Smart Wayfinding and Navigation (SWaN) Using High Accuracy 3D Location Technology *TRX Systems*	SWaN is a smart wayfinding and navigation system for indoor locations that provides individuals with real-time location information, en-route assistance, and situational awareness.
Pre-Trip Concierge & Virtualization	
Smart Travel Concierge System (STCS) *AbleLink Smart Living Technologies*	STCS is a suite of technologies for assessing transportation readiness, pre-trip planning and execution, and trip virtualization activities. STCS is meant to assist individuals with cognitive disabilities, allowing them to take fixed-route transportation independently and reduce their need to use costlier paratransit services.
Robotics and Automation	
Disability and Rehabilitation Research Projects Program (DRRP) on Robotics and Automation for Inclusive Transportation *Carnegie Melon University (CMU)*	DRRP is researching and developing cloud-based autonomy and shared robots located in and around transportation hubs. The project objectives include (1) identifying methods for acquiring and applying knowledge about traveler routines to support seamless changes in travel, (2) determining appropriate intervention methods for preemptively addressing barriers along a traveler's trip, (3) developing scalable methods for rich map information during user and robot navigation, and (4) developing cloud-based autonomy and shared hub robots that can provide assistance during daily travel.
Safe Intersection Crossing	
Safe Intersection Crossing for Pedestrians with Disabilities *Carnegie Melon University (CMU)*	Safe Intersection Crossing for Pedestrians with Disabilities is a mobile app that will be integrated with Surtrac, a real-time adaptive signal control system, to improve the safety and independent mobility of pedestrians with disabilities while crossing intersections. The mobile app will connect pedestrians directly to the traffic signal control system. The app will: 1) ensure adequate crossing times for pedestrians; 2) alert the pedestrian of potential hazards (e.g., curbs, vehicle present) during crossing; and 3) if additional traveler route information is provided, streamline pedestrian travel time.

Description of Evaluation Metrics

This section provides detailed descriptions of each evaluation metric, organized by the spatial, temporal, economic, physiological, and social (STEPS) framework. Shaheen et al. (2017) developed the STEPS framework to categorize the myriad of transportation equity barriers facing transportation system users. The framework identifies barriers along STEPS dimensions (Shaheen, Bell, Cohen, & Yelchuru, 2017). Researchers can apply the evaluation metrics for the measurement of an impact within the given category of the STEPS framework.

The research team developed metrics for the ATTRI projects based on a review of each project scope and the technological application. Then, within the context of each dimension, the research team identified and drafted the metrics that could be used to identify the impacts of the technology. The research team chose these metrics based on an assessment of whether the impacts could happen along a given dimension as a result of the technology. The research team also considered the likelihood of data availability to measure the identified impacts. Outside researchers and project stakeholders reviewed these impacts and provided comments to the project team, who then updated the metrics to incorporate their input. Table 2 lists the metrics; the scale at which to apply them (prototype, regional, national); and the suggested ATTRI projects to which to apply the metric to measure impacts.

The sections following Table 2 define the evaluation metrics and categorize them along each impact area of the STEPS framework. This section also provides an indication of the desired directionality, potential data sources, and units of measure.

STEPS Framework

The STEPS framework categorizes equity barriers to accessing transportation:

Spatial – Spatial factors that compromise daily travel needs (e.g., excessively long distances between destinations, lack of public transit within walking distance)

Temporal – Travel time barriers that inhibit a user from completing time-sensitive trips, such as arriving to work (e.g., public transit reliability issues, limited operating hours, traffic congestion)

Economic – Direct costs (e.g., fares, tools, vehicle ownership costs) and indirect costs (e.g., smartphone, Internet, credit card access) that create economic hardship or preclude users from completing basic travel

Physiological – Physical and cognitive limitations that make using standard transportation modes difficult or impossible (e.g., infants, older adults, and disabled)

Social – Social, cultural, safety, and language barriers that inhibit a user's comfort with using transportation (e.g., neighborhood crime, poorly targeted marketing, lack of multi-language information)

The desired direction of change of a metric is context-specific. For example, some systems are designed to allow users to do more with less, enabling greater efficiency and satisfying needs with less travel. Other systems are designed to overcome mobility challenges, and thus the desired outcome is greater travel. As a result, a metric may not change in the same direction; metric increases are the desired outcome for certain projects, and metric declines are preferable for other projects. Where applicable, the research team has indicated that the desired directionality of the metric is ambiguous.

Table 2. Evaluation Metrics

METRICS	SCALE			ATTRI PROJECTS						
Spatial	**P**	**R**	**N**							
Distance of travel		X	X	■	■	■	■	■	■	■
Distance of trip	X				■	■		■	■	■
Distribution of injuries/fatalities among target user population		X	X							■
Distribution of origins and destinations	X	X			■	■	■	■	■	■
Distribution of trip purpose	X				■	■	■	■	■	
Distribution of users			X	■	■	■	■	■	■	■
Intersections used	X									■
Mode split of travel		X	X		■	■	■	■	■	
Number of crossings	X									■
Route of trips	X						■			
Trip count		X		■	■	■	■	■	■	■
Walking distance	X			■						
Walking speed	X			■						

METRICS	SCALE			ATTRI PROJECTS						
Temporal	**P**	**R**	**N**							
Duration (time it takes) to cross	X				■			■		
Duration of public transit use		X		■	■	■	■	■	■	■
Duration of travel		X		■	■	■	■	■	■	■
Duration of trip	X				■			■		
Mode shift			X		■			■		
Number of cycles waited before crossing	X				■	■	■	■	■	■
Public transit ridership			X	■						
Time of crossings	X						■			
Time of injuries/fatalities at intersections			X							■
Time of public transit use		X					■			
Time of trips	X	X		■	■	■	■	■	■	■
Trip planning time	X			■	■	■	■	■	■	■
Vehicle miles traveled (VMT)			X	■	■	■	■	■	■	■
Wait time	X			■	■	■	■	■	■	■

	SCALE			ATTRI PROJECTS						
Economic	**P**	**R**	**N**							
Amount of fixed route public transit use (number of trips taken)	X									■
Commercial property income		X		■	■	■	■	■	■	
Commercial Scalability			X		■			■		■
Number of trips taken with professional support	X			■	■	■	■	■	■	
Number of trips taken without professional support	X			■	■	■	■	■	■	
Sales of enabling devices			X							■
Sales of SCAN			X		■	■	■	■	■	
SMART Standard to National			X							■
Traffic flow (vehicles per hour through intersection)	X									■
Use of the API	X			■	■	■	■	■	■	
User assessments of productivity	X			■	■	■	■	■	■	■
User cost of travel	X				■	■	■	■	■	
User income		X			■	■	■	■	■	
User spending	X			■	■	■	■	■	■	

METRICS	SCALE			ATTRI PROJECTS						
Physiological	**P**	**R**	**N**							
Accessibility		X		■	■	■	■	■	■	■
Accessibility perception	X			■	■	■	■	■	■	■
Ease of use perception	X			■	■	■	■	■	■	■
Happiness	X			■	■	■	■	■	■	■
Happiness perception		X	X	■	■	■	■	■	■	■
Health		X	X	■	■	■	■	■	■	■
Health perception	X			■	■	■	■	■	■	■
Mobility		X		■	■	■	■	■	■	■
Mobility perception	X			■	■	■	■	■	■	■
Safety		X	X	■	■	■	■	■	■	■
Safety perception	X			■	■	■	■	■	■	■

METRICS	SCALE			ATTRI PROJECTS						
Social	**P**	**R**	**N**							
Applicability to universal design			X	■						
Demographic profile of users		X		■	■	■	■	■	■	■
Ease of use	X									■
Equity of access to technology			X	■	■	■	■	■	■	■
Knowledge of transportation system	X				■			■		
Perception of blind person mobility			X	■						
Perception of independence	X				■			■		
Perception of safety of travel	X				■	■	■	■		■
Perception of safety of crossing	X									■
Public perception of ADA mobility			X		■	■	■	■	■	■
Public perception of device		X				■	■	■	■	■
Quality of life rating	X			■	■	■	■	■	■	■
Stress level of crossing	X									■

LEGEND	
ATTRI PROJECTS	
■ (1)	Smart Cane for Assistive Navigation
■ (2)	SMART Wayfinding Specification
■ (3)	AccessPath
■ (4)	Smart Wayfinding and Navigation (SWaN) Using High Accuracy 3D Location Technology
■ (5)	Smart Travel Concierge System (STCS)
■ (6)	Disability and Rehabilitation Research Projects Program (DRRP) on Robotics and Automation for Inclusive Transportation
■ (7)	Safe Intersection Crossing for Pedestrians with Disabilities
SCALE	
P	Prototype
R	Regional
N	National

Spatial Evaluation Metrics

Distance of travel represents the aggregate distance traveled by a population at the regional or national level. Distance of travel could be measured as the miles traveled by a population of geographic area, or the average trip distance of the population. The metric is meant to compare distance traveled before and after the deployment of an application.

Directionality: Typically, a decrease in the distance traveled represents a positive outcome as it may indicate that nearby resources and destinations are more accessible and lead to a decrease in environmental impacts (i.e., fewer personal vehicle miles traveled [PVMT] occur). It may also indicate that certain travel is no longer necessary. However, certain ATTRI-related projects may have the objective of increasing mobility and miles traveled, in which the desired directionality is in increase.

Potential Data Sources: Travel surveys, national or regional data sources (i.e., the National Household Survey), activity data

Units: Total miles traveled among population/total trips completed among population

Distance of trip refers to the total distance traveled per complete trip, inclusive of legs from origin to destination. This metric is meant to compare the distance traveled to complete a trip before and after the deployment of an application.

Directionality: For individual trips, a decrease in distance traveled per trip is typically a positive outcome, representing greater efficiency and less effort for meeting travel needs.

Potential Data Sources: Activity data, travel surveys

Units: Miles traveled/trip

Distribution of injuries/fatalities among target user population refers to the percentage of individuals that incur injuries (segmented into categories or types of injuries) and/or percentage of fatalities that occur while traveling among the regional or national population

Directionality: A decrease in injuries or fatalities universally is considered a positive outcome.

Potential Data Sources: Regional databases (i.e., the Statewide Integrated Traffic Records System), police records, local hospital records

Units: Number of injuries/population; number of fatalities/population

Distribution of origins and destinations refers to the percentage of trips that start and end within defined geographic areas

Directionality: Ambiguous – desired outcome varies depending on case-specific factors. For example, a community may want more trips to begin and end in commercial areas. The desired change in distribution of origins and destinations is highly context-specific.

Potential Data Sources: Activity data

Units: Number of trips beginning (or ending) within specified geographic area/total trips

Distribution of trip purpose refers to the share of trips with different trip purposes. Examples of trip purposes include commuting to school or work, recreational, running errands, and attending medical appointments.

Directionality: Given the variable is categorical, the desired directional change is ambiguous and context-specific to the project. A project may seek to increase trips of a certain purpose, such as work trips or medical trips, in which case the number of such trips can be measured in response to the evaluated project.

Potential Data Sources: Survey data

Units: Number of commute trips/total trips

Distribution of user refers to spatial distribution of home and work locations, which can be evaluated by specific attributes such as cognitive impairments, mobility limitations, visual impairments, and other types.

Directionality: The desired directionality is specific to the project objectives. For example, one objective may be to increase the accessibility of a technology of users within specific environments (e.g., rural environments, specific urban regions). Measurements may be focused on increasing the concentration or spread of user home or work locations; hence, the desired directionality is context-specific.

Potential Data Sources: Survey data, census data

Units: Number of users 75 years of age or older/total user population

Intersections used refers to the location of intersections that application users cross during a trip.

Directionality: The desired change in spread or count of intersections used is context-specific and it may be desirable for metrics derived from intersection use to increase or decrease. Certain projects may wish to change the type intersections used, where the amount of travel is the same, but routes are distinct.

Potential Data Sources: Activity data, survey data

Units: Cross streets of intersections crossed

Mode split of travel refers to the distinct travel modes used by a traveler during a complete trip (from origin to destination). Modes used can include: personal vehicles; carpooling; public transit; bicycling; and transportation network companies (TNCs), ridehailing, and ridesourcing, among others.

Directionality: Multimodal trips and trips that include shared or active modes are typically viewed as a positive outcome. However, metrics related to public transit use or other shared modes with higher occupancy may also be viewed as positive.

Potential Data Sources: Survey data, operator data

Units: Modes used/trip

Number of crossings refers to the number of intersection crossings per complete trip (origin to destination).

Directionality: The desired direction is context-specific in that intersection crossings may be preferred to increase or decrease depending on the project goal.

Potential Data Sources: Activity data, survey data

Units: Number of crossings/trip

Route of trips refers to the course taken to complete a trip from origin to destination.

Directionality: Ambiguous

Potential Data Sources: Activity data, survey data

Units: Coordinates of an individual's trip, recorded at intervals

Trip count refers to the number of trips completed by an individual per day.

Directionality: An increase in trip count could indicate increased mobility; however, an increase could also indicate inconvenience for individuals.

Potential Data Sources: Activity data, survey data

Units: Daily trips per person

Walking distance refers to the distance walked per trip.

Directionality: An increase in walking distance could indicate an increase in active mode use and mobility; however, high walking distances may cause difficulties for people with mobility disabilities.

Potential Data Sources: Activity data, survey data

Units: Miles walked/trip

Walking speed refers to the average travel speed for a walking trip.

Directionality: Typically, higher walking velocity is preferred

Potential Data Sources: Activity data

Units: Total miles walked/total duration (minutes) of trip

Temporal Evaluation Metrics

Duration (time it takes) to cross refers to the duration of time it takes a pedestrian to cross an intersection. People with disabilities may take longer to cross intersections or have difficulty crossing in the allotted time.

Directionality: A decrease in duration may be viewed as positive, as it reduces exposure time. Certain projects may seek to lengthen the duration of intersection crossing by providing more time for individuals with disabilities to cross the intersection at a more comfortable pace.

Potential Data Sources: Activity data, survey data

Units: Number of seconds to cross/intersection

Duration of public transit use represents the typical duration of transit trips among a population.

Directionality: Ambiguous. An increase could indicate increased public transit use, or it could indicate inefficient public transit.

Potential Data Sources: Activity data, survey data

Units: Average number of minutes of public transit use/day

Duration of travel represents the duration of time individuals spend traveling within a time period, such as a day.

Directionality: Typically, a decrease in duration of travel is viewed as positive. This indicates an increase in travel efficiency. However, an increase in travel duration can also indicate increased accessibility, allowing individuals to travel more.

Potential Data Sources: Activity data, survey data

Units: Average number of minutes spent traveling/day

Duration of trip refers to duration of a complete trip, from origin to destination.

Directionality: Typically, a decrease in trip duration is viewed as positive.

Potential Data Sources: Activity data, survey data

Units: Number of minutes/trip

Mode shift refers to the distribution of modes used by a population before and after an application is implemented or made available. This metric is meant to measure whether individuals have changed the modes they use.

Directionality: Typically, a shift toward active or shared modes is viewed as a positive effect.

Potential Data Sources: Survey data

Units: Percentage of population traveling with a particular mode

Number of cycles waited before crossing refers to the number of light cycles waited before a pedestrian crosses an intersection.

Directionality: A decrease in the number of cycles waited is a positive outcome.

Potential Data Sources: Survey data

Units: Number of light cycles waited/crossing

Public transit ridership refers to the count of individuals riding public transit in a specified network or geographic area.

Directionality: An increase in public transit ridership is typically considered a positive outcome.

Potential Data Sources: Public transit operator, survey data

Units: Number of individuals using public transit/day

Time of crossings refers to the time at which a pedestrian crosses an intersection. This differs from the duration it takes to cross an intersection.

Directionality: This is a temporal variable that could have multiple objectives, and thus has ambiguous desired directionality.

Potential Data Sources: Activity data, survey data

Units: HH:MM[1] of crossing at intersection

Time of injuries/fatalities at intersections refers to the time at which injuries or fatalities occur at an intersection; gathered for all injuries or fatalities at intersections for a population.

Directionality: Declines in injuries and fatalities are desired. Evaluations may seek reductions in injuries and fatalities at a certain time.

Potential Data Sources: Police data, hospital data

[1] HH:MM is a time format based on the 24-hour time reporting system.

Units: HH:MM of injury or fatality at intersection

Time of public transit use refers to the time at which individuals begin and end public transit trips throughout the day (e.g., an individual begins a trip leg on public transit at 08:00 AM and ends the trip leg on public transit at 08:20 AM).

Directionality: Context specific to the study

Potential Data Sources: Public transit operator, survey data, activity data

Units: HH:MM of start of public transit leg; HH:MM of end of public transit leg

Time of trips refers to the time at which the individual departed from the origin and the time at which they arrived at their destination.

Directionality: Ambiguous

Potential Data Sources: Survey data, activity data

Units: HH:MM of trip start; HH:MM of trip end

Trip planning time refers to the duration of time an individual spends planning a trip.

Directionality: A decrease in planning time is typically a positive outcome.

Potential Data Sources: Survey data

Units: Number of minutes spent planning/trip

Vehicle miles traveled (VMT) is typically used as a measure represent the average VMT per person across a population. This metric can be segmented by single occupancy vehicle trips, personal vehicle trips, or other types of vehicle trips.

Directionality: Ambiguous. Typically, a decrease in single occupancy vehicle miles is a positive outcome. However, an increase in vehicle miles traveled with shared modes (i.e., public transit, carpooling, carsharing) may be viewed as a positive effect.

Potential Data Sources: Activity data, survey data, operator data

Units: Average VMT per person

Wait time refers to the duration of time waited to use a mode.

Directionality: A decrease in wait time is a positive outcome.

Potential Data Sources: Activity data, survey data, operator data

Units: Minutes waited to access mode

Economic Evaluation Metrics

Amount of fixed route public transit use (number of trips taken) refers to the number of trips taken on fixed-route public transit over a period of time.

Directionality: Typically, an increase in fixed-route public transit use is a positive outcome.

Potential Data Sources: Activity data, operator data, survey data

Units: Number of fixed-route public transit trips/week

Commercial property income refers to income produced from the operation of a commercial property.

Directionality: An increase in commercial property income is a positive outcome.

Potential Data Sources: Real estate investors, commercial property owners

Units: Average income generated from commercial properties in a region/year

Commercial Scalability refers to the capability of a system to perform well under an increasing workload or scope.

Directionality: Increased commercial scalability is typically seen as positive.

Potential Data Sources: Performance data, manufacturer data, operator data

Units: Performance/size of system; efficiency/size of system; cost per device/size of system

Number of trips taken with professional support refers to the number of trips taken with professional support per time period.

Directionality: Typically, a decline is preferred in that reduced professional support indicates higher independence. There are cases in which increased travel with professional support is a sign of increased accessibility of that support.

Potential Data Sources: Survey data

Units: Number of trips taken with professional support/week

Number of trips taken without professional support refers to the number of trips taken without professional support per time period.

Directionality: Typically, an increase is preferred in that reduced professional support indicates higher independence. There may also be cases in which increased travel with professional support is a sign of increased accessibility of that support. Broadly, trips with or without professional support may be a useful metric for evaluating some projects.

Potential Data Sources: Survey data

Units: Number of trips taken without professional support/week

Sales of enabling devices refers to total sales of a device, technology, or service that enables mobility, such as a smartphone app that identifies wheelchair accessible vehicle (WAV)-accessible routes.

Directionality: Increased sales is typically positive, indicating demand for the product.

Potential Data Sources: Sales data from supplier

Units: Total national sales of enabling device/year

SMART Standard to National refers to the number of clinical apps built using the Substitutable Medical Applications, Reusable Technologies (SMART) framework. SMART is an open, standards-based technology platform that enables developers to build apps that can connect to health data systems.

Directionality: An increase in the number of apps that use the SMART standard may be positive, as it indicates improved access to health data and care.

Potential Data Sources: SMART

Units: Number of apps developed using SMART standards across the nation

Traffic flow (vehicles per hour through intersection) refers to the number of vehicles that pass through an intersection per hour.

Directionality: Ambiguous, depending on the objective of the project. Traffic calming or increased walking time for persons with disabilities may seek to reduce the traffic flow, whereas other projects may seek to increase it.

Potential Data Sources: Traffic sensor data

Units: Number of vehicles passing through intersection/hour

Use of the application programming interface (API) refers to API usage or the number of requests per minute made to API.

Directionality: An increase in API usage may indicate increased use of the application for accessibility, which is a positive effect.

Potential Data Sources: Owner of API

Units: Number of requests made to API/minute

User assessments of productivity is a metric used to gauge how ATTRI application users feel about their productivity. It can be gauged from user responses to survey questions on whether they felt they had saved time or changed the number of tasks they were able to complete through use of the ATTRI application.

Directionality: Desired outcome is an increase in perceived productivity.

Potential Data Sources: Survey data

Units: Perceptions of time savings or tasks completed

User cost of travel refers to travel expenses incurred by a user during a complete trip.

Directionality: A decrease in user cost is a positive effect.

Potential Data Sources: Survey data, operator data, activity data

Units: Travel expenses/complete trip

User income refers to the distribution of the household income of a user population (i.e., the percentage of users that fall within discrete household income categories).

Directionality: Devices may increase income by increased job accessibility. However, in terms of the income of users, a diversity of income levels may indicate that a technology or service is widely accessible.

Potential Data Sources: Survey data, census data

Units: Percentage of users with a household income between $50,000 to $75,000

User spending refers to a user's total spending on generalized expenses over specific time period. This can include expenditures on travel, groceries, consumer items, and other expenses.

Directionality: Ambiguous. An increase could indicate increased mobility (e.g., the user is able to go shopping more often) or it could indicate that the user must spend more due to a lack of flexibility.

Potential Data Sources: Survey data

Units: Total money spent by user/month

Physiological Evaluation Metrics

Accessibility metrics can refer to the accessibility of a site or amenity by users, in particular those users with cognitive, mobility, auditory, or visual impairments.

Directionality: Scores increase as accessibility increases.

Potential Data Sources: Survey data, expert evaluations

Units: Ordinal survey responses

Accessibility perception refers to the perception of accessibility by people with and without disabilities.

Directionality: A perception that a site, technology, or service is accessible is positive.

Potential Data Sources: Survey data

Units: Accessible, unsure, inaccessible

Ease of use perception refers to the perception of the ease of use of transportation services (e.g., fare payment stations, station stalls) for people with and without disabilities.

Directionality: The perception that an application is easy to use is a positive outcome.

Potential Data Sources: Survey data

Units: Easy to use, unsure, difficult to use

Happiness refers to an individual's happiness, scored using happiness indicators. Typically, happiness is reported on various self-reported scales.

Directionality: A high happiness score is typically considered a positive outcome.

Potential Data Sources: Survey data, expert evaluation

Units: Use nine happiness domains as a scoring card

Happiness perception refers to happiness (or satisfaction) with a transportation system for meeting mobility needs.

Directionality: A high happiness perception is a positive outcome.

Potential Data Sources: Survey data

Units: Ordinal survey responses

Health refers to health of a population as measured by health indicators. A potential scoring system to use is the Center for Disease Control and Prevention's leading health indicators, which were developed to assess the health of the country and motivate action to improve health. The 12 topic areas include: 1) access to health services; 2) clinical preventive services; 3) environmental quality; 4) injury and violence; 5) maternal infant and child health; 6) mental health; 7) nutrition, physical activity, and obesity; 8) oral health; 9) reproductive and sexual health; 10) social determinants; 11) substance abuse; and 12) tobacco use (National Center for Health Statistics, n.d.).

Directionality: Ambiguous (dependent on indicator)

Potential Data Sources: HealthyPeople.gov database, other medical databases

Units: Varied; depends on the health topic being measured

Health perception refers to an individual's perception of health as a result of the current transportation system.

Directionality: Higher ratings are a positive outcome.

Potential Data Sources: Survey data

Units: Ordinal survey responses

Mobility is a metric that is used to evaluate a population's ability to use existing transportation modes to complete trips and tasks. It can be used to compare mobility for people with and without disabilities.

Directionality: If measuring trip duration, a positive effect would be to minimize the difference in duration between trips taken by those with and without disabilities.

Potential Data Sources: Activity data, survey data

Units: Trip duration for persons with and without disabilities for similar trips

Mobility perception refers to an individual's perception of mobility across a transportation network.

Directionality: The perception of high mobility is a positive outcome.

Potential Data Sources: Survey data

Units: High mobility, unsure, low mobility

Safety refers to the number of safety incidents (e.g., injury, crime) that occurred during a time period.

Directionality: Fewer safety incidents is a positive effect.

Potential Data Sources: Police reports, hospital records, survey data

Units: Number of safety incidents per hundred riders per day

Safety perception refers to an individual's perception of safety (e.g., risk of injury, vulnerability to crime) in a transportation network.

Directionality: A positive outcome is that individuals feel safe.

Potential Data Sources: Survey data

Units: Safe, unsure, unsafe

Social Evaluation Metrics

Applicability to universal design refers to the design and composition of an environment so that it can be accessed, understood, and used to the greatest extent possible regardless of age, size, ability, or disability (Center for Excellence in Universal Design, n.d.) (Rosetti, 2006). Universal design is summarized in seven principles: 1) equitable use, 2) flexibility in use, 3) simple and intuitive use, 4) perceptible information, 5) tolerance for error, 6) low physical effort, and 7) size and space for approach and use.

Directionality: Increased applicability to universal design is typically considered positive.

Potential Data Sources: Survey data, expert evaluation

Units: Use seven principles of universal design as a scoring card

Demographic profile of users refers to the distribution of age, household income, employment status, gender, or other demographic characteristics of users.

Directionality: A diverse array of users from different demographic groups that aligns with the population or is aligned with disadvantaged demographics is typically viewed as positive. If a given group is not represented, it may indicate accessibility challenges.

Potential Data Sources: Self-reporting survey data, census data

Units: Percentage of users who are 75 years of age and above

Ease of use is defined as how easy the product is to use by its intended market.

Directionality: Positive outcomes for ease of use measurement include high success rates in completing trips, a decrease in the duration of time to complete a trip, and high user satisfaction.

Potential Data Sources: Survey data

Units: Success rate in completing trip; change in time it takes to complete trip; user's subjective satisfaction

Equity of access to technology can involve many factors including the knowledge or training to be able to use a technology, the affordability of technology, language barriers, and physical ability to use a technology.

Directionality: High scores on knowledge, affordability, and physical ability to use are desirable.

Potential Data Sources: Survey data

Units: Ordinal survey responses for knowledge, affordability, and physical ability to use

Knowledge of transportation system refers to an individual's knowledge of available transportation resources for an agency or mode (e.g., paratransit to supplement fixed-route bus systems).

Directionality: A high awareness of available resources is a positive result.

Potential Data Sources: Self-reporting survey data

Units: Number of resources known/number of resources available

Perception of blind person mobility refers to the ability to navigate transportation systems and other infrastructure using existing assistive devices (e.g., canes).

Directionality: A high perception of blind person mobility is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Perception of independence refers to an individual's perception of independence from or while using the device or service.

Directionality: An increase in independence is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Perception of travel safety refers to an individual's perception of safety from or while using the device or service.

Directionality: An increase in safety perception is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Perception of safety of crossing refers to an individual's perception of safety while crossing the street and using the prototype.

Directionality: An increase in safety perception of crossing is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Perception of social skills refers to an individual's perception of social skills while interacting with other people.

Directionality: An increase in social skills perception is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Public perception of the Americans with Disabilities Act (ADA) mobility is an aggregate measure of the public's perception of how accessible amenities (e.g., shops, transit) are for people with disabilities.

Directionality: High scores for the public's perception is a positive outcome.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Public perception of device refers to the public's perception of the usefulness, affordability, and practicality of the device.

Directionality: High perceptions of usefulness, affordability, and practicality are positive outcomes.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses per characteristic

Quality of life rating refers to the subjective well-being of an individual across a range of areas. The World Health Organization has developed instruments to assess an individual's quality of life. These cover six broad domains (physical health, psychology, level of independence, social relations, environment, and spirituality/religion/personal beliefs) and produce a total of 100 items to assess on a five-point scale (1-5) (World Health Organization, n.d.).

Directionality: Ambiguous; it depends on the item being rated.

Potential Data Sources: Survey data, World Health Survey

Units: Ordinal survey responses per area

Stress level of crossing refers to the stress caused by concerns of injury, collision, or inability to cross the street within a timely manner.

Directionality: A low rating for stress is desirable.

Potential Data Sources: Self-reporting survey data

Units: Ordinal survey responses

Demonstration of Impact Assessment

This section demonstrates how to evaluate the impacts of an ATTRI application using the evaluation metrics described in this report. For this demonstration, the research team analyzes the impacts of the SMART Wayfinding Specification, one of the seven applications that received development funding from the USDOT. The SMART Wayfinding System project report provides the data used in this analysis and further information on this application (Davies & Stock, 2019).

Project Background

AbleLink Smart Living Technologies developed, tested, and published the SMART Wayfinding Specification and cloud-based support tools for creating route instructions. AbleLink developed the specification and support tools to enable individuals to easily locate, download, and enhance standardized routes based on personal needs with the SMART Ready wayfinding app. The app provides travel-related support to users with cognitive disabilities. To do this, the app uses GPS and visual, audio, and vibration prompts to help individuals with cognitive disabilities navigate fixed route transportation independently. The SMART Wayfinding Specification adds new features, expands functionality, and provides a mechanism to interface with the SMART Route library (Davies & Stock, 2019).

Several participating organizations tested the integration of the specification and app using field implementation activities. These participating organizations included Ability Beyond of Bethel, Connecticut; ARCA of Albuquerque, New Mexico; Black Hills Works of Rapid City, South Dakota; and Merakey of Coraopolis, Pennsylvania. This white paper uses data obtained from the field implementation project conducted with Merakey in western Pennsylvania. Merakey staff were trained to use the SMART Route Builder, two SMART Route Libraries, and the WayFinder app. Staff members worked with the travel participants to learn how to use the WayFinder app. The section below summarizes the results from the field implementation project.

Field Implementation Data

Merakey collected three sets of discrete data during the field implementation project. These included: 1) the number of trips attempted and completed per participant; 2) a survey of street crossing skills; and 3) a survey of social skills. Merakey also tracked trips during the project, but these data were not available in the project report.

Twenty-three participants (N=23) participated in the study. The participants ranged in age from 23 to 62, with an average age of 39.3 (σ=12.58). The participants included individuals with intellectual and developmental disabilities. Some participants had physical disabilities. Participants attempted to complete trips using the Smart Wayfinding technologies. A “trip” consisted of a round-trip journey, from boarding the boarding bus stop to the destination bus stop, and then returning on a bus back to the point of origin. Thus, a complete trip included two bus rides. Table 3 summarizes the participants’ trip data.

Table 3. Merakey Trip Data

Subject	Trips Attempted (ride to and from destination)	Trips Completed (without Complication)
AB01	10	0
AB02	8	8
AB03	7	4
AB04	4	3
AB05	8	7
AB06	8	6
AB07	9	8
AB10	5	5
AB11	8	7
AB12	8	7
AB13	4	3
AB14	4	4
AB15	4	2
AB16	8	7
AB17	8	8
AB18	4	4
AB19	6	6
AB20	9	2
AI01	4	4
A102	11	10
AI03	2	2
AI04	8	8
AI05	11	11
Total	158	126

The research team issued the street crossing skills survey and the social skills survey to participants before and after the field implementation project to measure the change in those skill areas as a result of the project. Transportation readiness scores for each of the surveys represent percentage value, and the maximum value is 100. Ten participants (N=10) completed both the pre- and post-test street crossing skills survey. Fourteen participants (N=14) completed the pre- and post-test social skills survey. Table 4 and Table 5 show the paired data sets for the surveys.

Table 4. Street Crossing Skills Survey Data

Pair	Pre-Test	Post-Test
1	76	93
2	59	81
3	56	56
4	74	96
5	41	41
6	85	63
7	85	89
8	69	100
9	69	85
10	87	93

Table 5. Social Skills Survey Data

Pair	Pre-Test	Post-Test
1	95	99
2	100	88
3	89	71
4	71	100
5	86	75
6	93	100
7	83	95
8	95	99
9	95	90
10	90	93
11	89	87
12	58	83
13	90	93
14	93	100

Methodological Considerations

With the limited data available, the research team was able to demonstrate three metrics: trip count (spatial), perceived safety of crossing (social), and perceived social skills (social).

The first metric compares the number of trips before and after the project implementation. Given that the data were paired, several options were available to explore the change in metrics and statistical significance of that change. Parametric tests are tests that rely on a number of assumptions but are the most powerful of statistical tests. They are called parametric because one of the required assumptions is that the data follow predefined (e.g., parameterized) distribution. For the conventional t-test, the assumption is that the data follow a normal distribution or that the sample is large. If the sample size is large, then the assumption of normality in the distribution of data need not hold. Also, the data type ought to be of ratio scale, where the distance between observations is a quantifiable number, and the distance between measurements does not change across the scale. This excludes ordinal data, such as the Likert scale, where it is known that “Strongly Agree” is greater than “Agree,” but the distance between those measurements is different from the difference between “Agree” and “Disagree.” The order of the responses is clear, even though the magnitude of the difference across them is not objectively quantifiable. When these collective conditions are met, the paired t-test is an appropriate application to statistically test whether there is significant difference between the paired before-and-after responses.

Therefore, the research team analyzed the latter two metrics using a paired sign test at the 5% significance level. The sign test is a simple statistical method for evaluating whether a significant difference exists between paired observations, and it is typically used for small sample sizes (Dixon & Mood, 1946). The sign test is typically used to assess when sample sizes are small (<30) or when the data are ordinal in nature. Samples less than 30 are almost always considered small. Samples greater than or equal to 30 are large enough to be used for parametric t-tests. There are conditions in which a parametric t-test is still valid to use at smaller sample sizes. If the variable being tested is normally distributed, then the t-test can be used at lower sample sizes. Achieving a definitively normal distribution shape rapidly becomes more difficult as sample sizes fall, but it is still possible. Another key determination is whether there are outliers in the sample, which further degrade the value of the t-test. If the sample is not large and not normal, or is not large and has outliers, then a non-parametric test should be considered (Weiss, 1999). Non-parametric tests evaluate whether the distributions of data collected before and after are different, whereas the t-test is used to evaluate whether a sample mean is distinct from a given population or test value. Tests of the mean are more powerful when possible, but the data conditions for the latter two metrics suggest that a non-parametric test is more appropriate and can still be used to draw conclusions. Different tests have different underlying assumptions supporting their use. The considerations discussed here are specific to the data applied in this demonstration. There are of course a number of statistical tests that apply to different situations with their own underlying assumptions and a deep literature that should be consulted in the consideration and selection of the appropriate test for a given set of data.

For other applications like modeling, sample sizes would typically have to be larger than the minimums needed for statistical tests. The exact size of the sample model depends on the specific type of modeling and the number of independent variables tested. Simpler models, like ordinary least squares regression, can produce statistical significance with smaller sample sizes (<100) with one or two independent variables if there is a strong association with the dependent variable.

Most metric calculations are best assessed using before-and-after measurements, as conducted in the data presented here. However, before-and-after measurements are not always practical or obtainable. If before-and-after measurements are not possible, retrospective measurements—where respondents provide an assessment of direction of metric change based on their experience—is a good substitute. A challenge with before-and-after data is that it requires advance planning in evaluation, where the intervention is known, and the evaluation is in place before it is applied. When people supply the before-and-after data, it is also a challenge to maintain sustained engagement with the sample, which is necessary to ensure that the same respondents provide paired observations, as shown in this demonstrative analysis. A consistent pairing of observations, which controls best for the issues that are idiosyncratic to humans, produces the most controlled assessment of intervention impact. However, a before-and-after analysis can still be executed with human observations even if they are not paired. Another approach that can be considered is the use of a control group. Control groups in the context of most transportation projects are groups of potential users who could use or receive the intervention but do not. The control group is compared to the treatment group, which does receive the intervention, to evaluate differences in whatever is measured. If the response of the treatment is significantly different from the control group, then it provides evidence that the intervention was effective. Control groups are valuable in this regard but need to be selected carefully. Control groups should be as similar to the treatment as possible. That may include similarities in demographic attributes, local environment, and other attributes that could influence how the intervention does or does not impact the metric of interest. In practice, this can be difficult to do, particularly in transportation, where many potentially unseen factors may influence behavior or response to a treatment. Absent this similarity, other factors may influence the control group, which can obscure the true measurement of impact. However, when properly designed, the use of a control group can add clarity and robustness to findings about the impact of a given intervention, since it can provide a direct measurement of the impacts that occur in the absence of the intervention.

At small sample sizes, the distribution of unpaired before-and-after measurements can be more significantly influenced by the attributes within the sample population that may not match the distributions of attributes in the population. At larger sample sizes, differences between the sample and general population from which it is drawn are still expected to be present, but they are less likely to influence the key measurements in ways that would influence the broader conclusion about the likely impact of the intervention on the broader user population. As with any study, evaluations should consider data collection methods to ensure systematic biases in the sample are minimized. Further, evaluations should consider and specify and limitations that may exist as a result of metric design or the data collection that informs that metric design. The section that follows briefly describes measurements that can be made with data that are available from existing ATTRI projects.

Example Metric Evaluation

The data available enables an exploration of the selected metrics and how they changed as a result of a specific ATTRI project. As noted earlier, the data are comprised of paired before-and-after observations of trip count, street crossing ability, and social skills. The intervention was the SMART Wayfinding Specification tool. This section summarizes the findings from the application of the three metrics: trip count, perceived street crossing ability, and perceived social skills.

Evaluation of Trip Count

Prior to participation in the field implementation project, none of the respondents traveled via fixed-route public transit. At the completion of the study, 126 of 158 trips were completed "without complication"—an 80% completion rate. At the 5% significance level, this confidence interval ranges from 73% to 86%. Conceptually, this implies that if the sample were redrawn in the same way and measurements of the SMART Wayfinding Specification tool were redone, it would be 95% certain that aggregate percentage of trip completion would be between 73% and 86%.

Determining whether this average and range is considered successful is an exogenous judgment. Is an 80% completion rate successful? In this scenario, setting a null hypothesis before data collection can be useful. The null hypothesis defines the baseline value against which the performance of the intervention is measured. It can be drawn from a value measured in the absence of the intervention, either before it is applied or with a separate control group that is not exposed to the intervention. It can be arbitrarily selected as a target to beat. In the case of these data, if the null hypothesis was that the target completion rate would be 75%, then the findings would show that the completion rate was not significantly higher than that target. However, this conclusion is contingent on the selected target. It is important that experimenters set target metrics before performing the analysis to avoid bias.

Absent from this data are "before" measurements of trip completion, which would enable the measurement of change. For example, if participants were only completing 70% of their trips prior to the intervention, then the data would suggest a statistically significant improvement. For this analysis, the null hypothesis is somewhat of an arbitrary target. That target may be informed by a measurement of the completion rate that was prevalent before the intervention. Alternatively, it may be informed by expectations that are defined by the application project team. The selection of a target rate for the null hypothesis can be useful for providing definitions of success for the intervention.

Another way to inspect this data is via the individual level. Because the aggregate proportion may be influenced by a single individual who is taking a lot of trips and completes most of them, the inspection of the individual proportions is useful to ensure that measured impacts are fairly distributed across the sample population. In this case, the research team finds that the average percentage of completed trips by individuals within the sample is 82%, suggesting that the aggregate measurement is not significantly influenced by a minority of users completing many trips. Indeed, 16 of the 23 respondents had a completion rate above the aggregate average of 80%.

Perceived Street Crossing Ability

Because of the large sample size of trips, evaluation of trip counts can rely on the parametric test of proportions to define confidence intervals, though it lacked a true "before" measurement to assess change. The survey data provides a before-and-after measurement, but the sample size is more limited since only the individuals can be counted. The application of the sign test with a 5% significance level ($\alpha=0.05$) can be used to compare the difference between the participants' before and after use of the SMART Wayfinding app. The sign test is a simple nonparametric test that analyzes the signs of the different scores of the paired data. The research team's null hypothesis (H_0) is that the median difference between the scores is zero, while the alternative hypothesis (H_1) is that the median difference is positive. In other words, the alternative hypothesis is that there is an increase in street crossing skills after use of the SMART Wayfinding app. The number of positive or negative differences (whichever is smaller) is the test statistic.

The street crossing skills survey sample (n=10) resulted in seven positive differences, one negative difference, and one tie. Ties are excluded, so the sample was reduced to eight (n=8). The value of the test statistic is 1 (the number of negative differences, which is smaller than the number of positive differences). Next, the research team calculated the p-value, which is the probability of observing only one negative difference under the null hypothesis, using the binomial test. The team obtained a p-value of 0.0351. Because the p-value is less than the significance level ($0.0351 < 0.05$), the team can reject the null hypothesis. The results of the paired sign test indicate that use of the SMART Wayfinding app led to a statistically significant improvement in perceived street crossing ability.

Perceived Social Skills

Similar to the evaluation of street crossing, the sign test can be applied to analyze the results of the social skills survey. Once again, the research team chose a 5% significance level. The null hypothesis (H_0) is that the median difference between the scores is zero, while the alternative hypothesis (H_1) is that the median difference is positive. The survey (n=14) resulted in 5 positive differences and 9 negative differences. The test statistic is 5. Next, the research team obtained a p-value of 0.2120. Because the p-value is more than the significance level ($0.2120>0.05$), there is not sufficient evidence to reject the null hypothesis. The results of the sign test indicate that use of the SMART Wayfinding app did not lead to a significant difference in perceived social skills.

This analysis of preliminary field studies indicates that the SMART Wayfinding app had a positive effect on the sample population’s street crossing skills. Twenty-three participants were part of the field study. Of these, twenty-two were able to complete at least one fixed-route public transit trip without complication. In total, 80% of the 158 trips attempted were completed without complication. The analysis indicates that the SMART Wayfinding app may lead to an improvement in perceived street crossing skills; however, the research team was unable to find a significant difference in perceived social skills after use of the app.

Discussion and Recommendations

The analysis presented above is conducted with different types of data that were collected to assess the SMART Wayfinding app. Similar analyses can be applied to any metric that is defined to evaluate performance of ATTRI projects. The appropriate test will depend on the data available, its structure, and the needs of the evaluation.

There are numerous methods of analysis that can be applied depending on the structure of the data. Certain findings from research at the prototype level can sometimes be extrapolated to estimate the impact on the population. Any extrapolation of results to population level findings should consider how the sample of test users aligns with the population the intervention is trying to serve. This can be challenging for the population targeted for ATTRI technologies because they may not match the demographic profile of the general population of a region, which can be evaluated using the U.S. Census American Community Survey. However, the general population served by a specific ATTRI technology could be different, and there may be no such data on the population attributes of similar completeness. If there is a good estimate of key population distributions such as those for age and gender, then the sample can be evaluated for the degree to which it matches the population. This may inform interpretations or the potential for the findings to be extrapolated to a broader population of potential users.

Demographic population attributes may not be the core attributes that influence how a user responds to a technology. For example, in some cases, gender may significantly influence response, whereas, in other cases, gender may be irrelevant to differences in response. In other cases, a core attribute influencing response to a technology could be attitudinal, whereas social views impact adoption and use. Another example relates to the location of an individual’s home or employment, which may influence the ability of the person to make use of the technology in their everyday life. It can sometimes be challenging to anticipate whether less visible attributes of the population have a core influence on how the population will respond. Focus groups or earlier studies can sometimes help anticipate the importance of such attributes.

Large samples typically reduce such concerns because they allow for demographic and other attributes to be more effectively represented in the sample. However, if the method of sample collection favors certain populations, then the bias can remain and needs to be corrected by weighting. One example of this is the survey of existing system or technology users to assess impact on behavior. Frequent users of a technology may be more likely to take a survey about their use of the technology. Frequent users also may be more likely to be impacted by the technology. Therefore, the sample, even if large, may be biased toward more frequent (high impact) users than the general population of users. Under such scenarios, weighting by frequency of use may be more important than weighting by demographics. In the context of ATTRI technologies, attaining large sample sizes can be challenging since ATTRI technologies often target specific populations. Ideally, the sampling of users is diverse enough, either through a large unbiased sample or through stratification, to adequately cover the main demographic attributes of the population to eliminate concerns of major bias in the sample. Evaluators will have to make context-specific judgments of the appropriateness of their sample and attribute distributions with regard to extrapolating findings to the user population targeted by the technology.

To extrapolate findings from a sample, the size and composition of the broader user population should be understood. Most importantly, it is necessary to understand the specific population to which the results will be extrapolated. This includes understanding the size of that population and how key attributes of that population may differ from the sample. The research team could not extrapolate the data exercise presented since the size and composition of the user population was unknown.

Several approaches are possible for future data sets that may be more complete. One method describes an approach using weighting, which scales impacts from the sample up to the population. The other approach discussed uses random draws from the sample to simulate the population.

Extrapolating to the Population Using Weighting

Future projects can take the following steps when extrapolating results to a population from a sample:

1) *Determine the size of the user population:* The size of the user population may be the number of people who would be able to use or are likely to use the evaluated product or system. This is context-specific to the product at hand and specific to how users are impacted by it. For example, the user population for a product aiding the visually impaired would naturally be constrained by the size of the visually impaired population. This size would serve as the upper bound of the user population. An additional consideration constraining this size is the product adoption rate. Not everyone with the impairment will use the product, so a forecasted or assumed adoption rate needs to be applied. Taking the example of the visually impaired population, a recent (2016) estimate suggests that 7.7 million people in the United States have a visual disability, according

to the Cornell University Employment and Disability Institute (EDI) (National Federation for the Blind, 2019). If a product is expected to be eventually adopted by 2% of that population, then the size of the user population would be estimated to be at least 154,000.

2) *Determine the composition of the population:* In this hypothetical example, 2% of the population will have some demographic and attribute composition. For some populations with disabilities, demographics may be well specified. Yet for the others, they are completely unknown. In the example of the visually impaired, high-level sociodemographics are at least generally specified. Cornell's EDI estimates that 55% of the visually impaired population is female and that 41% are over the age of 65 (National Federation for the Blind, 2019). This breakdown does not reflect the general population of the United States. Adoption of a product may be equally distributed across the population (e.g., where 55% of the population users are also female), or it may be weighted towards certain demographics. It may be the case that a specific product is more likely to be adopted by males, or predominantly by older people. In such circumstances, the forecasted attributional balance of the population may not reflect the general population, and a unique distribution of the user population needs to be assumed or measured based on expected adoption within the population.

   Some attributes may not have any impact on how a product is used. Understanding the gender or age balance of the anticipated user population only matters if the testing of a prototype reveals that these attributes have a substantive influence on how the product is used.

3) *Evaluate how the impacts of the sample vary by participant attributes*: As part of any prototype testing, impacts may vary across the sample. As a hypothetical example, it may be the case that males exhibit stronger impacts from a given product, even though product adoption in the population follows the gender balance of the general population. In such circumstances, when extracting to the population, there is the need to establish weights on attributes that are determined to be associated with stronger or weaker impacts.

4) *Generate weights based on the distribution of sample and population attributes*: The main objective of weighting is to appropriately scale impacts from a sample to accurately reflect how they will translate to the population. In the unidimensional example, where impacts are only weighted on one attribute, a simple division (population % / sample %) of the relative percentages of one attribute is appropriate. If more than one attribute is used, the calculation of the weight is the same (population % / sample %), but the percentages are constructed from combinations of attributes (e.g., males, 45 to 55 years old). For example, in the simple case of gender, if it is determined that:

   a. Males are more impacted by a product than females, <u>and</u>
   b. Females are more represented in the forecasted user population than males (e.g., 55% to 45% as in case of the visually impaired population), <u>and</u>
   c. The proportion of males in the sample of the prototype evaluation is not equal to the balance expected in the user population (e.g., 35% females to 65% males), <u>then</u>
   d. The weight needs to scale down the impact of males from the sample to the population. This weight would be computed as (45% / 65%) for men and (55% / 35%) for women.

   Multi-dimensional weights would require consideration of the balance of other attributes in the sample and population. It is also important to note the weighting can be applied to rebalance the sample to the population on any number of attributes, but evaluators should not get carried away.

Practically, there is a limit to the number of attribute distributions that are known for the sample and for the population that caps the number of combinations that can be considered. Weights only need to be considered for the key attributes that significantly influence how people respond to a product. Often, this can be captured by weighting on one or two main attributes.

5) *Apply computed weights to the sample observations to scale to population impacts*: With the weights appropriately computed, the impacts can be expanded to the population level. The participant impacts in the sample can then be multiplied by the weights to produce a “weighted impact” for each observation in the sample. The sample distribution of impacts (as percentages) is then effectively weighted to reflect the distribution that would be observed in the population. To understand aggregate scale impacts, the distributions or average impacts defined by the re-weighted sample can be multiplied by the population size. This produces estimated population level impacts that can be reported as distributions as well as other average or aggregate forecasts.

Extrapolating to the Population by Simulating the Population from Draws from the Sample

The procedure above defines how results from a sample can be extrapolated to the population. The weighting method above is useful for generating population-level distributions or average impacts by re-weighting the sample to better balance the distribution of impacts expected by a population adopting a product. One alternative method is the simulation of a large population. This approach proceeds with Steps 1 through 3 in the same way. At Step 4, weighting is achieved by randomly drawing observations from the sample and then inserting them into the population according to their expected distribution within that population. The effect is the same and in some ways can provide more flexibility with population-level projections. This approach requires the capacity to simulate a large number of individual observations (equal to the size of the population), which is not always practical or feasible. Simulating a population also works better when the sample size is large (several hundred), so that diversity in the draws within specific attributional cohorts can be better achieved. In this case, using simulation to scale to the population can offer some advantages with modeling and interpretation of results. For this procedure, complete Steps 1 through 3 as defined above, then follow the alternative Step 4 (called Step 4s) and onwards, as detailed below:

4s) *Draw the population of individual cohorts from the sample*: To weight the effects through simulation, observations can be randomly drawn from the sample and fit into the population. To continue with the example of the visually impaired population, in which 55% are female and 45% are male and the population size is 154,000, researchers can draw from the sample to fill this population with observations. Step 4 considered a sample comprised of 35% females and 65% males. The simulation can randomly draw (with replacement) from the sample and create observations within the population. The draws must occur within the cohort of interest. When developing the population of females, the sample draw must only be taken from the females in the sample. This proceeds as follows:

a) Determine the number of females in the sample (e.g., 70)
b) Order these females in a list from 1 to 70
c) Generate a random number from 1 to 70; call this q
d) Pick the *qth* female from the sample
e) Assign this female and all her attributes to an observation within the population

f) Repeat these draws and assignments until spaces allocated to females in the population are filled (e.g., 35% x 154,000 = ~53,900)

g) Repeat this process, drawing from males, who would number 130 in this sample, for males in the population (e.g., 65% x 154,000 = ~100,100).

5s) *Compute population statistics based on the simulated population*: Sample-side underrepresented females are now appropriately represented in the population, and sample-side overrepresented males are now also appropriately represented. In this hypothetical example, since males were more impacted by the product than females, their influence on aggregate statistics in the population is diminished. That is, average impacts in the population will appear less than they would have in the sample. In both cases, observations from the sample are repeated in the population many times, and this is because the sample is the only detailed information available to estimate population impacts. The simulation brings that sample to the population scale with the appropriate balance.

Simulation has advantages in that many analyses, including cross-tabulations, can be reconstructed at the population level in a relatively straightforward manner. Additionally, it can be done for multiple dimensions of attributes simultaneously. For example, if age is also an important influencer of impacts, then draws can be done from bins that define both age and gender simultaneously. The main drawback of simulation is that, for large populations, it can be computationally intensive. This can sometimes be addressed through scaling the population down, without much loss of information or resolution (e.g., one observation in the population represents 10 people).

As noted in this discussion, extrapolating impacts to the population can be conducted in a number of ways. The method chosen should appropriately fit the metrics and the objectives of the analysis. For future evaluations of ATTRI projects, the research team recommends selecting the evaluation metrics during the formulation of the study design. Further, early considerations should be made regarding whether extrapolating to the population is necessary and the method to follow for doing so. Information on the population is needed, and determining whether this information is available is an early but critical step.

Proper planning will inform proper data collection that enables population comparisons before and after project implementation. It is also important that projects collect a large sample size where possible as well as before and after responses for each respondent. If that is not possible, projects can also collect retrospective data. Data that do not provide a benchmark for behavior before the analysis can limit the ability to draw conclusions effectively.

Conclusion

Within the last decade, the public and private sectors have developed many projects to address mobility for travelers with disabilities. Notable developments include: 1) multiple projects that add accessibility features to navigation apps and use smartphone features to assist with navigation, 2) multiple efforts to provide open-source accessibility-related information for pre-trip planning, 3) shared mobility service providers adding wheelchair accessible vehicles to their fleets, and 4) improving upon wheelchair designs to allow for higher levels of autonomy. The review of industry developments also uncovered projects that focus on enabling safe intersection crossing.

A variety of different types of metrics can be used to evaluate projects that impact the travel behavior and well-being of persons with disabilities as well as the industry that supports those technologies. These metrics can be applied to projects at different scales (i.e., prototype, regional, or national) and along different dimensions (i.e., spatial, temporal, economic, physiological, and social). The metrics are defined so as to be generalizable and relevant as technologies in the accessibility space evolve. This paper shows the computation of a few metrics using available data from a USDOT ATTRI application. Within this demonstration, several limitations were encountered. To begin, the data applied in this demonstration were not developed with the given metrics defined beforehand. That is, they were applied to serve as a proxy for the metrics designed after their collection. Ideally, the metrics used for an evaluation are known in advance, and the data are collected to specifically support the computation of those metrics. Future researchers should determine metrics in advance and collect baseline date before a pilot is conducted. In practice, even the most well-planned evaluations can encounter challenges that force adaptation as data limitations arise. In addition, the available data had a small sample size, so the distribution of unpaired before-and-after data is more likely to be influenced by the specific personal attributes of the sample population and may depart more significantly from that of the broader population. Such data limitations can be addressed by sound planning in data collection and collecting larger, but unbiased, sample sizes. Researchers may face data limitations regarding the expense of collecting comprehensive data, particularly in the cases where the user population is small to begin with. Some data may also be sensitive or proprietary information. For example, certain identifiable information may need to be redacted to better protect user privacy. Future ATTRI projects can mitigate such limitations with advanced evaluation planning early in the project that defines the key metrics of interest and the data sources that can be used to compute those metrics.

Future ATTRI projects can also apply the STEPS framework through evaluation planning. The metrics presented here within the STEPS framework provide a foundation for this planning, but they need not be considered as the total scope of possible metrics that can be used in future evaluations. Evaluation planning ultimately does not begin with a definition of metrics but with the definition of key questions of interest related to impact assessment. These questions may explore how the intervention impacts the user along the dimensions of the STEPS framework. Those questions can be translated into hypotheses that are testable statements defining how the intervention may impact the user. It is at that point that performance metrics, such as those listed in this paper, can be linked to the hypotheses of interest. The data needs of the evaluation then follow from the performance metrics. Once the metrics of interest are known, the types of data needed to compute those metrics become apparent. The evaluation plan can proceed to collect that data for the duration of the evaluation.

Metrics should be chosen with careful consideration of feasibility and project expectations. The following are examples of some factors to consider during metric selection:

- Is the study sample size sufficient to perform analysis on the metric?
- What data collection methods (e.g., surveys, activity data collection, publicly available data sets) fall within the project budget and timeline?
- Will the measurement of the metric address the key question or hypothesis about the technology?
- Are there security concerns with collecting and storing data?

The impacts of ATTRI-related projects may change as they are scaled from prototype to regional or nationwide deployment. Extrapolation of pilot scale results to a wider deployment is an exercise that should always be done in consideration of the sample used in the pilot study. Pilot studies with samples representative of the user population can be extrapolated with greater confidence. The larger the unbiased sample, the more reliable the extrapolation. However, large biased samples can be worse for extrapolation than smaller unbiased samples, even though the larger samples will exhibit greater statistical confidence. Statistical tests never factor in the data collection method, and so the validity of any extrapolation is a function of judgment of the quality of the sample to represent the population. Even if the potential for extrapolation is limited, prototype projects can still be used to develop "best practices" or "lessons learned" that guide large-scale deployment. Researchers may be able to identify barriers to deployment or impact and develop strategies to minimize their influence. Another consideration in scaling is the metric itself. Certain metrics, such as a mode shift, may scale intuitively from prototype evaluations to a broader user population. Other metrics may be more challenging and require additional information about healthcare. For example, scaling impacts on trips taken with or without professional support requires knowing not only the population using professional support for mobility but also the degree to which that population travels with that support. In addition, it may also be challenging to scale metrics that are more qualitative in nature. For example, scaling changes in measures of happiness by the population might be a more challenging exercise in abstraction. While such scaling may doable, it may simply be useful enough to know that the evaluated intervention seemed to improve the sample's qualitative attribute measure. This may serve as evidence that the intervention is worth scaling, even if the magnitude of the impact is ultimately not easily predictable.

The research team recommends conducting future research that explores an additional potential metric for a prototype, regional, or nationwide deployment of "increase in productivity of caregivers." This measure, which is well-examined in the field of labor economics, represents a significant benefit of accessible transportation and is worth highlighting.

As ATTRI and related projects continue to evolve, the technologies supporting the mobility and accessibility needs of persons with disabilities will continue to need evaluation for the purposes of performance measurement. How the performance of each technology is measured depends upon its purpose and function. Some technologies will impact movement, while others may influence safety, social well-being, or economic welfare. The focus of any evaluation should be to define the key questions that will yield insights on the technology effectiveness and to apply the appropriate metrics that address those questions. Such metrics, if appropriately designed and supported by data collection mechanisms, can advance our understanding of technologies capable of improving mobility, accessibility, safety, economic vitality, and quality of life for a diverse array of populations.

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Appendix A. Glossary

Table 6 on the following page provides a glossary of potential evaluation metrics for technologies that aim to improve mobility for people with disabilities. The evaluation metrics follow the STEPS assessment framework. Each entry includes: 1) the metric definition, 2) the unit of measure, and 3) whether the metric is applicable at the prototype, regional, and/or national level.

Table 6. Glossary of ATTRI Evaluation Metrics

Metric	Definition	Example Units Not the only units that can be used	Prototype	Regional	National
SPATIAL					
Distance of travel	Represents an aggregate number at regional or national level. Could be miles traveled for population of geographic area, or average trip distance per population	miles traveled/population; average miles traveled/trip		X	X
Distance of trip	Distance traveled per trip	miles traveled/trip	X		
Distribution of injuries/fatalities among target user population	Percentage of individuals who incur injuries (segmented into categories or types of injuries) and/or percentage of fatalities that occur among the regional or general population	# injuries/ population; # fatalities/ population		X	X
Distribution of origins and destinations	Percentage of trips that start and end within defined geographic areas	# trips beginning (or ending) within specified geographic area/total trips	X	X	
Distribution of trip purpose	Share of trips with different trip purposes	# commute trips/total trips	X		
Distribution of users	Demographic distribution (age, education, income) of users of ATTRI application OR Distribution of users with different types of disabilities (e.g., cognitive impairments, mobility limitations, etc.)	# of 75 years old or older users/total user population			X
Intersections used	Location of intersections used by ATTRI application users	Cross streets of intersections crossed	X		
Mode split of travel	The distinct travel modes used by a traveler during a complete trip (from origin to destination)	Modes used/trip		X	X
Number of crossings	Number of crossings per complete trip (origin to destination)	# crossings/trip	X		
Route of trips	The course taken to complete a trip from origin to destination	Coordinates of an individual's trip, recorded at intervals	X		
Trip count	The number of trips completed by an individual per day	Daily person trips		X	
Walking distance	Distance walked per trip	miles walked/trip	X		
Walking speed	Average travel speed for a walking trip	total miles walked/total duration of walking trip	X		

Metric	Definition	Example Units Not the only units that can be used	Prototype	Regional	National
TEMPORAL					
Duration (time it takes) to cross	Duration of time it takes a pedestrian to cross an intersection	# seconds spent crossing/intersection	X		
Duration of public transit use	Represents typical duration of transit trips among a population	Average minutes transit use/day		X	
Duration of travel	Represents time spent traveling among a population	Average minutes spent traveling/day			
Duration of trip	Number of minutes to complete an individual trip	# minutes/trip	X		
Mode shift	Distribution of modes used by population *before* and *after* application is implemented or made available.	% population traveling with mode, before and after			X
Number of cycles waited before crossing	Number of light cycles waited before the pedestrian crosses the intersection	# light cycles waited/crossing	X		
Public transit ridership	Count of individuals riding public transit in a network or geographic region	# of individuals using public transit/day			X
Time of crossings	Time at which a pedestrian crosses an intersection	HH:MM of crossing at intersection	X		
Time of injuries/fatalities at intersections	Time at which fatalities occur at intersection; gathered for all injuries/fatalities at intersections for a population	HH:MM of injury or fatality at intersection			X
Time of public transit use	Number of individuals using public transit at certain times throughout the day	# of people using public transit at HH:MM		X	
Time of trips	The time at which individuals are using public transit throughout the day	HH:MM of trip start; HH:MM of trip end	X	X	
Trip planning time	Duration spent planning a trip	# minutes spent planning/trip	X		
Vehicle miles traveled (VMT)	Can represents average vehicle miles traveled (VMT) across a population. Can be segmented by single occupancy vehicle trips, personal vehicle trips, or any vehicle trip	Average VMT per Person			X
Wait time	Duration of time waited to use mode	Minutes waited to access mode	X		

Metric	Definition	Example Units Not the only units that can be used	Prototype	Regional	National
ECONOMIC					
Amount of fixed route public transit use (number of trips taken)	Number of trips taken on fixed-route public transit per period of time	Number of fixed-route public transit trips/week	X		
Commercial property income	Income produced from the operation of a commercial property	Average income generated from commercial properties in a region/year		X	
Commercial Scalability	The capability of a system to perform well under an increasing workload or scope	(Performance, efficiency, or cost per device)/(number of customers or size of system)			X
Number of trips taken with professional support	Number of trips taken with professional support per time period	Number of trips taken *with* professional support/week	X		
Number of trips taken without professional support	Number of trips taken without professional support per time period	Number of trips taken *without* professional support/week	X		
Sales of enabling devices	Total sales of device, technology, or service that enables mobility (i.e., smartphone app that identifies WAV-accessible routes)	Total national sales of enabling device/year			X
Sales of SCAN	Total members nationwide of SCAN, a nonprofit HMO that provides healthcare coverage to Medicare beneficiaries	Total members of SCAN/year			X
SMART Standard to National	Number of clinical apps built using the SMART (Substitutable Medical Applications, Reusable Technologies) framework	Number of apps built using SMART standards across nation			X
Traffic flow (vehicles per hour through intersection)	Number of vehicles that pass through an intersection per hour	Number of vehicles passing through intersection/hour	X		
Use of the API	API usage (number of requests per minute made to API)	# requests made to API/minute	X		
User assessments of productivity	User responses to survey questions on whether they felt they had saved time or had changed the number of tasks they were able to complete due to use of ATTRI application	Perceptions of time savings or tasks completed	X		
User cost of travel	Travel expenses per user during a complete trip	Travel expenses/complete trip	X		
User income	Distribution of household income of user population	% users that fall within household income range		X	
User spending	A user’s total spending on generalized expenses over specific time period	Total money spent by user/month	X		

Metric	Definition	Example Units Not the only units that can be used	Prototype	Regional	National
PHYSIOLOGICAL					
Accessibility	Accessibility of site or amenity by users with: cognitive, mobility, auditory, or visual, impairments.	Ordinal survey responses		X	
Accessibility perception	Perception of accessibility by people with and without disabilities	Accessible Unsure Inaccessible	X		
Ease of use perception	Perception of ease of use of transportation services (e.g., fare payment stations, station stalls) for people with and without disabilities	Easy to use Unsure Difficult to use	X		
Happiness	An individual's happiness in regard to happiness indicators	Use of 9 domains of happiness as scoring card (GNHUSA, n.d.)	X		
Happiness perception	Satisfaction/happiness with transportation system for meeting mobility needs	Ordinal survey responses		X	X
Health	Health in regard to health indicators	Use of 12 health indicators as scoring card (National Center for Health Statistics, n.d.)		X	X
Health perception	Perception of health as a result of current transportation system	Ordinal survey responses	X		
Mobility	Ability to use existing transportation modes to complete trips and tasks	Trip duration for person with a disability compared to trip duration of similar trip for person without a disability		X	
Mobility perception	Perception of mobility across a transportation network	High Mobility Unsure Low Mobility	X		
Safety	Number of safety incidents (e.g., injury, crime) that occurred during a time period	Number of safety incidents per hundred riders per day		X	X
Safety perception	Perception of safety (e.g., risk of injury, vulnerability to crime) in a transportation network	Safe Unsure Unsafe	X		
SOCIAL					
Applicability to universal design	The design and composition of an environment so that it can be accessed, understood, and used to the greatest extent possible by all people regardless of their age, size, ability, or disability (Center for Excellence in Universal Design, n.d.) (Rosetti, 2006).	Use seven principles of universal design as a scoring card			X

Metric	Definition	Example Units Not the only units that can be used	Prototype	Regional	National
Demographic profile of users	Distribution of age, household income, employment status, gender, etc. of users	% users that fall within demographic category out of total users		X	
Ease of use	Defined as how easy the product is to use by its intended users.	• Success rate in completing trip • Change in time it takes to complete trip • User's subjective satisfaction	X		
Equity of access to technology	Equity of access can involve many factors including: the knowledge or training to be able to use a technology, the affordability of technology, language barriers, and physical ability to use a technology	Ordinal survey responses for knowledge, affordability, and physical ability to use			X
Knowledge of transportation system	Knowledge of available transportation resources per agency or mode (e.g., paratransit to supplement fixed-route bus systems)	Number of resources known/number of resources available	X		
Perception of blind person mobility	Ability to navigate transportation systems and other infrastructure using existing assistive devices (e.g., canes)	Ordinal survey responses			X
Perception of independence	Perception of independence from or while using the device or service	Increased Same Decreased	X		
Perception of safety of travel	Perception of safety from or while using the device or service	Increased Same Decreased	X		
Perception of safety of crossing	Perception of safety while crossing the street and using prototype	Increased Same Decreased	X		
Public perception of ADA mobility	Perception of how accessible amenities (e.g., shops, public transit) are for people with disabilities	Ordinal survey responses per amenity			X
Public perception of device	Public response to usefulness, affordability, and practicality of device	Ordinal survey responses per characteristic		X	
Quality of life rating	The subjective well-being of an individual across a range of areas – physical health, psychological health, independence, social life, environment, and other areas.	Ordinal survey responses per area	X		
Stress level of crossing	Stress caused by concerns of injury, collision, or inability to cross street within a timely manner	Ordinal survey responses	X		

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